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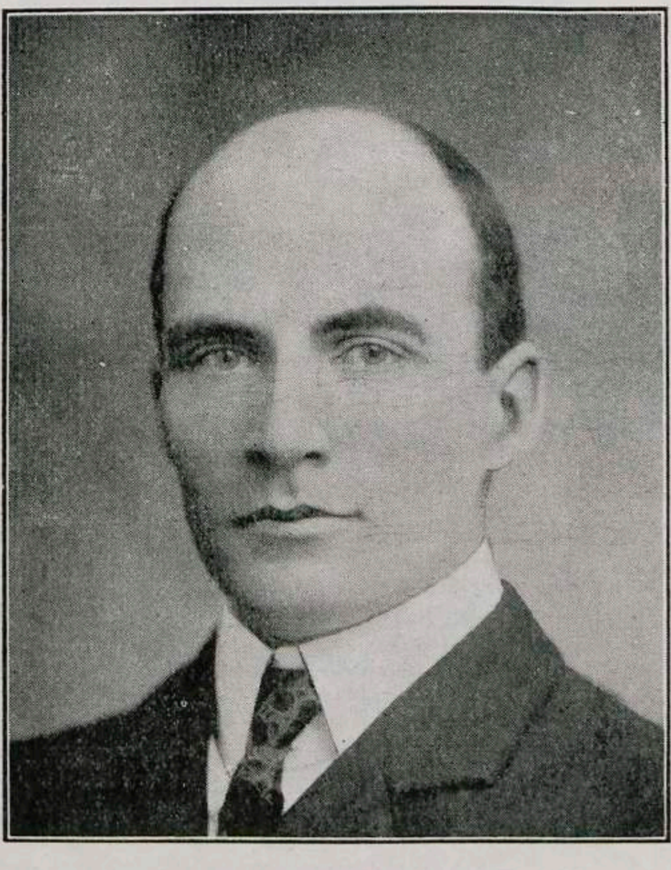

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VOL. X DECEMBER, 1919

PROCEEDINGS—WESTERN AUSTRALIAN INSTITUTION OF ENGINEERS
(Incorporated).

GENERAL MEETING HELD AT THE INSTITUTION'S ROOMS ON APRIL 9, 1919.

PRESIDENTIAL ADDRESS.

BY C. E. CROCKER.

We can look forward to great advances in engineering in the next few years, provided the economic and industrial conditions permit. Doubtless means will be found to surmount the economic position if the industrial conditions permit. The progress of the world will depend on an equitable adjustment of the social and industrial problems with which it is at present faced.

While it is recognised that the engineer has done great things towards winning the war, and, in fact, that war has become principally an engineering problem, it must not be overlooked that in the everyday life of the community, and in the future development of industry and living, the engineer must fill an important part. The engineer must divert and apply to peace conditions many of the discoveries and developments of science which have been applied to the war. To engineers are due the suggestion or working of most great industrial schemes which provide the employment of and welfare of the people. Frequently the engineer's position, with such schemes, does not receive the prominence it justifies, but he should make himself familiar with the social and industrial problems of the community in which he lives, as it is largely on his efforts and work that the future of the country depends. Particularly is this so in an undeveloped country like Western Australia. That country is in the safest and strongest position in peace as well as in war which can produce within its boundaries the greatest part of its requirements of raw materials and supplies.

Before the war there were many industries carried on solely in Germany, and it was considered they could not be

successfully carried on elsewhere. In consequence of the exigencies of the war, means have been found not only to develop but to make them profitable in various of the Allied countries. During the war most countries have developed and established industries which will make each more self-supporting and self-contained. War has to that extent benefitted those countries whose resources were undeveloped before. Australia (but, unfortunately, Western Australia to the least extent) has shared in this developmnt, and a number of important industries have come into being in the Eastern States.

Some of those industries founded on war requirements will cease to exist, and others, for the product of which there is a good Australian demand, will in any case continue operations, while between these two extremes there are the class of industries the permanence of which depends on equitable and peaceful industrial conditions.

By peaceful I mean something in the nature of peace. For some years we have ceased to expect anything approaching absolute peace in industrial matters, but the industrial world has adjusted itself to the average amount of disturbance. It is obvious, however, that the limit of disturbance and turmoil which can be surmounted has nearly been reached. Unless industrial conditions at least not much worse than those which existed before the war are soon realised there will be litttle likelihood of new works being undertaken, and there will not be the necessary demand for the output of those industries already established to keep them going. The result must be the slacking off in production and decrease of employment, with a consequent further decline. It is to be hoped the common sense and better education of the people will prevent the development in England and Allied countries of the terrible state of affairs now existing in Europe, as a consequence, apparently, of German intrigue in Russia. The only satisfaction we can feel is that those troubles and horrors are to a large extent recoiling on the Germans themselves.

It is the duty and desire of every Australian engineer to utilise Australian made material in every possible manner, and by so doing assist to develop and maintain those manufacturing undertakings already established, whilst promoting others. But unless those industries can supply at a reasonable price compared to the prices in other countries, the development of our natural resources will be seriously handicapped. The imposition of exceedingly high tariffs to support manufacturing may result in great harm, as there is a point in the cost of establishing or operating every undertaking beyond which it is impossible to go. When that point is passed the undertaking will not be established, or if already in existence, will have to cease,

and both the Government and manufacturers will be deprived of revenue they would have received had the costs been lower.

It seems to me there is great danger of that happening by constantly raising the tariff to support the Australian manufacturers, and that it has already occurred to some extent and prevented developments of primary resources which might have otherwise been made. Western Australia particularly suffers from high tariffs, as not only is the cost of development thereby increased, but this State does not benefit by the extra expenditure which goes to the Eastern manufacturers.

Australia, and especially this State, with its limited population, is essentially a country where development of primary resources is more urgent and important than the establishment of secondary industries. It is only by the development of our primary industries, such as pastoral, mining, agricultural and timber, that a permanent stability of the country can be established, and the population increased so it will be sufficient to support those secondary industries we all desire to see, but which must have a certain local demand to assist them in competing with their products in outside markets. It is to be hoped the policy of increasing tariffs in support of manufacturers will not be carried to the point of smothering our very important primary industries. Experience of the past indicates that every rise of Customs duty is followed by a corresponding increase in price by the local manufacturers, and it remains possible for the outside manufacturers to still compete while the consumer has to pay the higher price. If the higher duty was effective in stopping the imported article and the Australian manufacturer maintained the old price, the tariff would benefit the manufacturer and not handicap the consumer. It is, of course, necessary in some cases for the manufacturer to raise his prices on account of increased wages and cost of supplies, but there are conspicuous cases where, as we are all aware, the local prices are merely adjusted to meet the imported price, and the use of the former is not increased as it should be.

Although in Western Australia we have not during the war experienced the good times and industrial activity which the Eastern States have experienced, consequent on the great expansion of manufacturing there, it is quite possible on that account we shall feel less reaction in consequence of the termination of the war.

The construction of glass bottle works, and the progress which has been made towards the establishment of freezing works and cement works, are the most satisfactory developments towards new industries of the past year. All are works which the State needs, and they should be successful. The cement works are of particular interest to engineers, as the requirements for cement in engineering works and roads is constantly

increasing. If the alkali works, of which a good deal has been heard, and for the building of which there appears to be a fair hope, are established, they will do much to promote other industries and the utilisation of the natural resources of the State. In these there is much of interest to the engineer, and we must look to development of primary industries, and particularly to agriculture, to provide the population which is necessary before we can have an extensive demand for the solving of the engineering problems involved in the secondary manufacturing industries.

Agriculutral conditions in Western Australia, which have proven so difficult in the past, may yet be overcome by the application of engineering knowledge to farming. The farmer, like many another, is turning more and more to the engineer and machinery to meet the tasks he encounters. During recent years, owing to shortage of horses and labour, the introduction of machinery on the farm has progressed rapidly. Oil and gas engines have become quite familiar machines to the farmer, and in many parts of America the distribution of electric current through extensive rural districts has been accomplished, to the great convenience of the farmers. Farm tractors have done much to assist the agriculturist. When we read of a 50,000-acre wheat farm equipped with twenty-eight tractors, plowing up to 392 acres in one day, we realise their importance to the farmer. The use of machinery and motors on the farm should add an interest which will help to make the boys more satisfied to take up farming and remain there.

Motor traction on the roads is well worth the attention and study of our local engineers. Their application as feeders to the railways should bring many distant farms into reasonable communication with the markets. They may also prove practical for use in opening up new country instead of constructing railways, at least until the settlement is sufficient to justify a railway. Tractors and trailers of the caterpillar type will successfully negotiate almost any country without roads, but the building of a road for tractor traffic provides at once the good road so much needed in all country districts, while the construction of a railways leaves the road problem still to be dealt with. This road problem, which is now recognised as being so important to the community, is receiving a great deal of increased attention in the Eastern States, and should do so here. The great waste which occurs in the making and maintaining of roads in so many places is palpable to all. If our roads engineers could impress on the governing bodies the great waste of money which occurs by saving a little capital in improperly making a road in the first place, and then letting the road, such as it is, go to wreck through lack of prompt and proper maintenance, it would be a long step towards the realisa-

tion of good roads. The proper construction of a road at a larger capital expenditure will show a great ultimate saving of public money, over an inferior cheaper road requiring large expenditure on repairs and early reconstruction. Whatever the type of road constructed, however economy requires that repairs should be made promptly and constantly before it is destroyed and requires rebuilding. We see many cases of this where a few pounds spent on prompt maintenance would save many pounds in the end.

Some interesting tests of the tractive effort required on different kinds of roads have been made, which are very convincing of the waste of energy which occurs in operating traffic on bad roads. Trials were made with a 2-ton truck, and gave the following result:—Earth road, slightly muddy, 5.78 m.p.g.; gravel road, fair condition, 7.19 m.p.g.; gravel road, excellent condition, 9.39 m.p.g.; bituminous macadam, usual repair condition, 9.48 m.p.g.; brick road, cement grout, fair condition, 9.88 m.p.g.; brick road, cement grout, excellent condition, 11.44 m.p.g.; concrete road, surface good, 11.78 m.p.g. Showing that 25 per cent. more petrol was required on an excellent gravel and 64 per cent. on the average gravel road than on a smooth concrete surface. Equally remarkable are the tests of the pull in pounds per ton of load with a horse-drawn wagon weighing three tons gross. These were:—Loose gravel, not packed, 263 lbs. per ton;; hard earth road, fine dust, 92 lbs. per ton; gravel road, good normal, 78 lbs. per ton; water bound macadam, 64 lbs. per ton; concrete base, asphaltic oil and screenings top, 49 lbs. per ton; unsurfaced concrete, 28 lbs. per ton. Showing that one horse on a good concrete surface would do practically what three were required to do on the usual gravel road.

In line with the rapid development of petrol traffic has been the extensive increase in the use of the electric vehicles for town use. Previous to the war, electric vehicles were in extensive use in America, but the petrol restrictions have caused them to be rapidly developed and utilised in England. So satisfactory were the first vehicles, that they have been adopted in great numbers, until such firms as Harrods Limited have a fleet of sixty, varying between one-half and two-ton capacity, and the Midland Railway Company operate a fleet of seventy-six of two and three tons capacity. There are in use in Perth two electric lorries of one ton capacity, and these have given the greatest satisfaction. One having a speed of 12 miles per hour has been in use for over two years, and has run 9,000 miles, doing up to 20 to 30 miles per day. During the time it has never been broken down or laid up for repairs beyond overhaul and attention to the battery. It is equipped with an Edison battery. The costs per 12 months are as follows:—Material (including tyres, oil and grease), £36 7s. 6d. = 1.64d.

per mile; electric current, £20 12s. = 0.93d. per mile; labor, exclusive of driver, £8 10s. 11d. = 0.39d. per mile. Total costs, £65 10s. 5d. = 2.96d. per mile. The other vehicle is rated at a speed of 20 miles per hour. It has not been in such constant use, but has proven entirely satisfactory, having run a total of 6,763 miles. The operating costs are:—Material (no tyres yet renewed), including oil ,grease and battery maintenance, £17 16s. 6d. = 0.63d. per mile; electric current, £68 19s. 2d. = 2.44 d. per mile; labor, exclusive or driver, £2 10s. 11d. = 0.09d. per mile. Total to date, £89 7s. 4d. = 3.17d. per mile. Perth being fairly level is especially suitable to electric vehicles, and they will certainly come into extensive use when they are available, as the cost of operating is greatly less than with petrol, and none of the delays are experienced, as the machines are always ready for work.

We can expect the greater part of the delivery and cartage work of Perth to be done in the future by electric vehicles, with much less noise and disturbance in the streets, and a great saving in costs of operating. The small electric passenger car should also be of most valuable use here for town work, like that of medical men. Not only are electric vehicles profitable to the owner, but they are well worth encouragement by the central electric supply authority. Although the current required for charging one vehicle does not in itself seem very great, when a number are in use the combined consumption totals a large amount. As an illustration of this, a fleet of fifty-two five-ton wagons in use by a delivery company in New York consumes 12,000,000 units annually for charging purposes. Another advantage to the central station is that to a large extent the charging can be arranged for off peak hours by fixing a lower charge for current consumed during that period, thus evening up the load curve, with a large increase of revenue.

The establishment of the Bureau of Science and Industry by the Commonwealth Government is a move in the right direction, and when placed on a firm footing it should do a great deal toward developing Australia, and co-ordinating the divided efforts of the various States in that direction. Western Australia is especially fortunate in having been selected as the site for one of the Forest Laboratories of the Bureau. The establishment here of the laboratory should lead toward methods being found to conserve our forest wealth and utilise the great waste of timber now occurring. In addition, it will be of assistance to scientists and engineers, as it is, I believe, to be equipped as a standardising and testing laboratory as well.

Not only should means be found to make some use of the timber waste which occurs at the saw mills, but there are millions of tons of timber destroyed annually in clearing opera-

tions which is not considered of value now, but for which it is a great pity some use is not found. If only a comparatively small value could be placed on that timber, it would greatly assist the farmer, and would have the additional effect of causing people to be more careful to prevent the spread of bush fires, which are the cause of much destruction of timber.

Engineers generally must take a keen interest in such work as that of the proposed Forest Laboratory and the Bureau of Science and Industry, as the line separating the Engineer from the Scientist is very feint. At the least it is the Engineer who develops and applies to industry the discoveries of the Scientist, and the two must always work closely together.

One of the greatest effects of the war has been to promote a campaign for saving and economy in all directions, and especially toward economy of coal. This has had two principal effects. One is the increased use of town gas, and the other the extensive consideration of schemes for the centralisation of electric power supply. In England and also in the Eastern Australian States the demand for gas for domestic use has increased so rapidly that the efforts of the gas undertakings have been taxed to the utmost to meet it, and in many cases they have not been able to do so. A few years ago those interested in gas supply feared that the improvement of electric lamps and cheapening of current would be the death of the gas business. Although electricity has practically superseded gas for lighting, on the other hand, the use of gas for cooking and heating purposes has rapidly increased.

The movement for the substitution of large interconnected electric generating stations, erected at suitable places, for the numbers of smaller plants, is growing stronger in England, in view of the great economy of coal it would effect. The Coal Conservation Sub-Committee appointed by the British Parliament, in their report on the cost of power production in the United Kingdom, estimate the present coal consumption for that purpose at 80,000,000 tons annually, and that by a suitable arrangement of larger central stations to supply this power, a saving of 55,000,000 tons per annum would be effected. In view of the coal situation and supply available, such an economy cannot long be ignored.

The proposal for the development of the Morwell coal deposit for the generation of electricity to be transmitted to Melbourne, a distance of 90 miles, is being pressed forward, and a Commission has recently been appointed to control the proposal.

The need of the present time for economy, together with the provision of the best possible conditions for the encouragement of manufacturing and industrial establishments, all tend

to the development of the central electric supply. The availability of such a supply is always a great inducement for the establishment of industries requiring power. The establishment for Perth and the metropolitan district of the electric supply from the Government station at East Perth already provides a very excellent service for the district extending from beyond Midland Junction to the Henderson Naval Base, with the exception of the supply in the municipal districts of Subiaco and Claremont, which still retain their own plants. During the past year, notwithstanding the non-arrival of much of the equipment, considerable progress has been made in the change-over of the services in Fremantle and Perth to the new system. The tramways in Fremantle have been changed, also the larger portion of the lighting, including that to North Fremantle and Cottesloe. In Perth, conversion has progressed under considerable difficulty, until all Perth, except Leederville, the residential portions of West Perth, and a part of the business district west of Barrack Street, has been changed. The lighting system of South Perth is now also on the new supply.

Without considering the much discussed question of the voltage and frequency adopted for the Government supply, there can be no doubt that the fact of the supply being available must assist in the establishment of industries. The current can be sold at a price which is considerably cheaper than steam power can be generated in the usual private plant, and which will more than compete with the gas engine when all capital, maintenance and repair costs are taken into consideration. The gas engine power costs look very attractive when only fuel is considered, but when full allowance is made for extra capital charges and the cost of repairs and maintenance, and extra operating charges which occur with the gas plant, and for the greater reliability and increased working capacity of electric drive, due to absence of interruption, the user generally finds in favor of the electric drive.

It is unfortunate that the electric supply of the metropolitan district is controlled by so many authorities. The result of this divided control is a considerable variation of the price at which current can be supplied to the power consumer in the different portions of the district. The Perth Gas Company controlled the electric and gas supplies until the undertaking was purchased by the Municipality of Perth. The concessions held by the company covered the Municipality of Perth, and gave them also the right to supply to any district lying within a five-mile radius of the Post Office, Perth, subject to the consent of the local governing body of the district. On the inauguration of the Government central power scheme, the Act of Parliament, known as the Electric Light and Power Agreement Act, 1913, fixed the relations between the Govern-

ment and the Municipality, and embodied the agreement for the Municipality to purchase oll current in bulk from the Government. That Act confirms the right of the Municipality to supply current (with the consent of the local authority) to "any Municipal Council or Local Board whose district is situate wholly or partly within a radius of five miles from the General Post Office," and provides that the Government will not supply unless the Municipality fails in its obligation to do so.

The provision would appear to be a very fair one, but the effect of the different rates for current it establishes is regrettable. By reference to a map of the metropolitan district it will be seen that the area coming within the provisions of the Act and over which the Municipality of Perth has the right to distribute and sell current extends from the Northern boundary of the Perth Road Board ,near Balcatta Beach, to the Southern boundary of the Jandicott Roads District, a distance of approximately 23 miles, and from the Eastern boundary of the Bayswater and Belmont Park Roads Districts to the coast, about 13 miles in the widest part, and includes Claremont, but not Cottesloe.

Although Fremantle Municipality have a similar right to supply within a given area, the Perth rights are prior where the areas interlock. Now it will be recognised that in all the areas outside of those controlled by Perth and Fremantle, the Government can supply either direct to the local body, or, with their consent, to the private consumer. The effect of all this is that the Government, which generates the current, can supply more cheaply than the municipalities, which have to buy from the Government and distribute and re-sell. In the same manner Perth and Fremantle can sell current more cheaply than those local bodies, such as South Perth, which purchase from the two principal municipalities. The result of the arrangement must work detrimentally, to a serious extent, to the various districts, and hamper the establishment of industries. An industry requiring a considerable amount of power will naturally, if possible, locate where power can be purchased directly from the Government at the lowest price, and secondly will prefer the area supplied directly by Perth or Fremantle, and will not be able to pay the price which would have to be charged in the other district, such as South Perth. Industrial establishments will, therefore, unless it is essential for them to be near the city, be driven out of the municipal areas, much to the detriment of those municipalities. This is not as it should be. It should be possible for any power user to establish his works in any permissible locality which may best suit his requirements, and be able to obtain the same rate for the current as at any other locality. There are numerous matters, such as access, rail

facilities, market, etc., which are the principal considerations, and would affect the power consumers' choice if the power rate was not different. This is a serious detrimental feature of the present arrangement of power supply in the metropolitan area. It might be rectified only by an Act of Parliament establishing and fixing a uniform scale of charges at which power should be supplied by all the authorities, if that were possible. But that would necessarily hamper the Government supply, and affect the use of the power, as such a rate would have to be sufficiently high to cover the costs of the municipalities and their profits.

The only satisfactory solution, and the one which would be the best for the whole area, would be that the whole of the supply and distribution should be controlled by a trust. Such a trust would then supply direct to all consumers at a uniform rate which would be the lowest possible, and power consumers could pick their site where other conditions were most suitable. The undertakings then would be able to supply at a lower price, and considerable capital expenditure in line duplication would be saved. Also the service could be extended by the Trust to any district requiring or justifying such extension, without the present complications which arise as a result of the different rights affected. The whole tendency of trust control would be for greater economy and better working. Such a system can never be as efficiently or smoothly operated under a Government or Municipality. The trust would have to be constructed with a nominal capital to cover the loan indebtedness of the present undertakings, and become responsible for the interest on and repayment of those loans, and profits would be divided between the Government and local bodies in proportion to their interest involved, or by arrangement, probably the Government loan being ultimately paid off. The personnel of the trust would be representative of the different interests involved. Details of the composition and working of such a trust would require working out, but are not insurmountable, and the result would be beneficial, as trust control of such a public undertaking is the only satisfactory system, and must eventuate in time.

(MAY 14, 1919.)

ON THE RAPID SEASONING OF JARRAH.

BY ALFRED TOMLINSON.

Within recent years considerable interest has been awakened in the timber industry in connection with the so-called artificial methods of seasoning timber. In Western Australia rapid seasoning methods have, hitherto, been largely unsuccessful. Positive results, however, have been obtained lately on Jarrah and Karri, and the purpose of this short paper is to introduce and analyse respectively the methods and results of these investigations.

Mr. H. D. Tiemann, of the United States Forestry Service, has probably done more than anyone else to foster the interest in kiln drying, and only those who have considered the problem can truly appreciate the work he has done. The author wishes to acknowledge his indebtedness also to Mr. C. E. Lane-Poole,* Conservator of Forests, and to Mr. A. McNeil, Millars' Timber & Trading Co., and also to the senior engineering students at the University, particularly Mr. T. Cullity, B.E.

Introduction.—Wood, next to stone, is doubtless the earliest material used by man, and has served his needs more than any other substance. Many kingdoms have risen and fallen and become extinct, as the forests have flourished, been wantonly destroyed and perished. Although wood has been in use so long and so universally, there still exists a remarkable lack of knowledge regarding its nature, and so it is often treated and used in a faulty and wasteful manner. The reason for this imperfect knowledge is probably due to the fact that wood is a direct product of vital processes, and thus necessarily presents variations, possessed by all living species, which place it in a category somewhat different from that of mineral or manufactured substances. Cellular structure in wood and the qualities that attract and nourish micro-organisms have no counterparts among the inorganic materials. Evidently, it is difficult to study timber for the purpose of establishing general laws. Thus, experience shows that all methods of seasoning are not suitable for all woods. However, as will be seen later, certain laws or principles have recently been established in regard to drying timber, and adjustments, obtained by direct experience, are merely required to select the proper method in any particular case.

Necessity for Seasoning.—Woods deteriorate, or fail, from use (wear and tear), exposure (expansion and contraction), age

* See Bulletin No. 1, W.A. Woods and Forests Dept.

(brittleness), decay (fungous diseases), fire, marine life and land life (woodborers); and they are defended more or less successfully by seasoning, internal and external treatment. The term seasoning, as is well known, refers to certain processes designed to remove water from timber. Woods dry, shrink, are sterilised and cured, and otherwise improved by these processes, as moisture greatly affects the physical properties, and the removal of excess of water causes the wood to dry, shrink, gain appreciably in strength and stiffness, and decrease in weight. The durability of the wood is also increased during the drying process owing to the preparations contained in the sap that are of an organic putrefactive nature undergoing radical alterations. The alterations are of such a nature as to suggest the changes that take place in fruits when they are sterilised and cured. Since it is natural for felled timber, dead wood, as with other product of life processes, to rot and decay, seasoning must be regarded as an artificial process. It may be noted that in nearly all cases seasoning precedes internal or external treatment, the latter, however, will not be dealt with in this paper.

Drying and Shrinkage.—It is an easy matter to merely dry wood, but it is difficult to dry it so that every part will shrink together. At the outset it must be recognised that drying wood is not simply a matter of evaporating moisture, as in the case when drying, say, clay or fabrics. Wood, when drying, checks or splits, more or less. This is due to the uneven drying out of the wood and the consequent strains exerted in opposite directions by the wood fibres in shrinking. However, as will be seen later, it is possible to control, more or less, this checking or splitting by arranging for the wood substance to be kept in a plastic state during the greater portion of the drying operations.

Drying combines two problems.—The drying of wood is an art which properly combines two distinct problems, viz.:— One has to do with the physical conditions involved in the extraction of the moisture without injury to the material, and the other is concerned simply with the means for evaporating moisture. These will now be dealt with in order.

Physical behaviour of wood under heat treatment.—Wood is composed of innumerable minute hollow structural units known as wood cells or wood elements, which form a network making up the wood tissue. These cells differ from one another in shapes and sizes, in the thickness and surfaces of their walls, and in the ways in which they are arranged. Briefly, the arrangements of the wood elements in softwoods is, on the whole, simpler than in the hardwoods, so that shrinkage effects in the former are not so complex as in the latter. It is obvious, therefore, that the seasoning of softwoods is a simpler proposition

than that of hardwoods. Of the materials associated with the wood elements by far the most important is water, which acts by distending the wood elements, and thus making them weaker and more pliable. *Fibre Saturation and Shrinkage.*—Freshly cut West Australian wood contains anywhere from 30 per cent. to 250 per cent. of the dry weight of the wood in water. If kept in the air long enough, the moisture content of the wood finally comes into equilibrium with that of the surrounding atmosphere, and may be taken as 9 per cent. to 12 per cent., depending on the season.

Observation shows that water exists in wood in two conditions:—

(i) As *free water* contained in the cell cavities (*i.e.*, small particles).

(ii) As *fibre moisture* absorbed in the cell walls (*i.e.*, hygroscopic).

When containing just enough water to saturate the cell walls the wood is said to be at the fibre saturation point. Any water in excess of this which the wood may contain is in the form or free moisture in the cell cavities. As might be anticipated, by likening the wood tissue to an ordinary sponge, removal of the free water has usually no apparent effect upon the properties of the wood except to reduce its weight, but as soon as any of the fibre moisture is removed structural changes take place in the cell walls and the wood begins to shrink. Since the free water is the first to be removed, shrinkage does not begin, as a rule, until the fibre saturation point is reached. In the case of Jarrah and other Eucalypts, and some of the Oaks, however, shrinkage begins well above this point. For most woods the fibre saturation point corresponds with a moisture content of 25 per cent. to 30 per cent. of the dry weight of the wood. With Jarrah, shrinkage begins even when green, with a moisture content of 70 per cent., say, and continues until dry. For this reason, it has been found difficult to obtain the fibre saturation point. This all-important point has, however, recently been established, its value being about 30 per cent., and the details of the investigation are given in Appendix II. It is believed that the contraction at first (green to fibre saturation point) is due to a form of collapse of the cells and afterwards (fibre saturation to dry) to the "true" shrinkage of the cell walls.

How wood dries.—Clearly, an understanding of the phenomena which takes place as wood dries is of fundamental importance. In all seasoning processes the removal of moisture is entirely by surface evaporation, and the interior water must pass from cell to cell until it reaches the surface. A movement of water between any two portions necessitates a gradient of

moisture condition, or a difference in temperature, and evidently the surface must be drier than the inside. Again, the "maximum" rate of drying is reached when moisture is evaporated from the surface of the wood just as fast as it is transmitted from the interior. Exactly how the moisture passes through the wood is not known. Experience justifies the belief, however, that if this rate of evaporation is exceeded the columns of free water, with their wick-like action, become interrupted or broken with air between, and a retardation of the transfusion of free water from the inside takes place: the fibre moisture begins to evaporate from the surface, which sets (*i.e.*, surface plasticity is destroyed), and a casehardening takes place. If this maximum rate is not exceeded, a continuous flow of the free water from the interior to the surface takes place until the free moisture has passed off and the fibre saturation point reached. On further drying, evidently the fibre moisture must pass outwardly to the surface through the substance of the cell walls themselves, and not, as the free water, through the cell cavities or pores. The fibre drying operation is now comparatively simple, although obviously much slower than when evaporating the free water. Thus all drying curves show a considerable slowing down near the fibre saturation point.

How wood may be injured in drying.—In drying, wood may be degraded or injured through checking or splitting, casehardening, honeycombing, warping or twisting, and collapse. These defects, as pointed out before, are caused by unequal shrinkage, and the matter is dealt with at length in Appendix I. Briefly, checking, casehardening and internal checking or honeycombing is due to the outside of the wood drying considerably faster than the inside; warping or twisting is due to uneven grain, irregularities and blemishes, or bad stacking; collapse is due to wet wood and high temperatures. Prong tests will indicate the state of strain or particular degrading tendency due to uneven drying across a section. Figure I shows sections cut from jarrah boards with a strip sawed from the centre of each section. If the outside is appreciably drier than the inside, but above the fibre saturation point, the stresses cause the prongs to curve outwards as at *A*. The degree of curvature may be taken as a measure of the tendency to check or split on the outside. If the outside of the board has reached the fibre saturation point and is appreciably drier than the inside, the stresses cause the prongs to curve inward as at *B*, and bind on the saw. This indicates casehardening, and, as before, the curvature may be taken as a measure of the tendency to inside checking or honeycombing. It must be noted that in prong tests the presence and type of objectionable stresses in the timber should be apparent immediately after sawing. The subsequent behaviour of the prongs when left in the air represents a de-

velopment which has materialised after the timber has left the kiln. (See Appendix I.)

Humidity in Drying.—Observation shows that if dry heat is applied to the wood the surface will become entirely dry and casehardened, often before the interior moisture is heated, let alone removed. The cause is due to the fact that the surface evaporation is too rapid; for the surface must be kept soft and moist, and the pores left open until all the moisture within has been evaporated from the surface. It has been seen that for successful drying, the surface evaporation should not exceed the rate at which the free moisture is transmitted from the interior. Evidently, the humidity of the air at the surface will be the controlling factor. For success it will be necessary then to arrange for the humidity (often 85 per cent. at commencement of operations) to be such that it will prevent the surface from drying much below its fibre saturation point until all the free water has evaporated. When the free water has finally evaporated, the crucial point in the drying has passed, and there is little danger then of injury to the wood. The relative humidity may then be gradually reduced (say, ultimately, to 40 per cent.) to remove the fibre moisture.

Seasoning Processes.—Three groups of processes are employed to season woods. They are air or yard seasoning, water-seasoning, and kiln seasoning. In general, from two to four years must often pass before one inch boards are dried by air seasoning. It is expensive to hold stock so long, and it is dangerous because of fires. In particular, it is believed that the climatic conditions obtaining in Western Australia militate against a reasonable control of air seasoning operations on the comparatively difficult to season native hardwoods, such as jarrah and karri. Air seasoning requires so much time, that it is frequently combined with some other method. Before woods are thus yard seasoned they are often soaked in water, and sometimes drying commenced by this method is completed in a kiln. Kiln seasoning originated with attempts to prevent warping and checking in special pieces. In the United States of America nearly all hardwoods, save those in large construction pieces, are now seasoned by the kiln method. Drying proceeds rapidly, and details, such as humidity, can be controlled in kilns as they cannot be in air or water seasoning. It is believed that the necessity of shortening the time required for the drying, and the advantages of producing uniform and reliable material will nowadays compel us to resort to artificial methods, and so kiln drying alone will be considered in what follows. There are many details and combinations, but the factors that influence kiln design and operation in all cases are circulation, humidity and temperature.

Conditions and Control for Evaporating Moisture in Kiln Drying.—Consideration will now be given to the second problem, before referred to, in the art of drying timber, namely, "the means for evaporating water in wood." On analysis, it is found that for a kiln to give satisfactory results it is necessary that the fundamental important conditions, *viz.*, circulation, humidity and temperature, should be under proper control. If any one of these conditions is faulty, bad results must be expected. In the dry kilns, moisture is removed from the timber by surface evaporation only, and this requires heat. If only a few pieces of timber are to be dried it is possible to heat them by radiation or conduction, but with a stack of timber the heat must be conveyed into the interior of the stack by convection or movement of the surrounding medium, usually air or steam. Again movement is required for the removal of the evaporated moisture. Evidently, movement or circulation is necessary for drying to take place at all, and so is of first importance. The humidity is of next importance, because upon it depends the control of the proper drying of the timber. We have seen that by using a high humidity the surface of the timber is maintained in a moist condition, while the water is being drawn from the interior of the wood: too low a humidity will generally result in checking, casehardening and honeycombing. The temperature depends upon the species and condition of the timber. Obviously, it is advantageous to have as high a temperature as possible, both for economy of operation and speed of drying, but the physical properties of the timber will govern this.

Theoretical analysis shows that the use of water vapour, below or above atmospheric pressure, with no air present as a circulating medium would be the most economical way to dry. In practice, however, owing to the practical difficulties arising, it is found that the air is the most efficient medium. Calculation shows that about 1,000 cubic feet of air are required to theoretically evaporate 1 lb. of water under kiln conditions, so that a large amount of air must be brought in contact with the wood in order to dry it. The proportioning of the kiln as well as the arrangement of stacking the timber to be dried also must be carefully studied (Figure 5). For it is necessary that the moving air come in contact with every portion of the timber to be dried. If the air stagnates when in contact with the timber, the temperature will drop and the humidity will rise to a condition of saturation, so that drying cannot take place and the timber will tend to rot. Again experience shows that the natural air movement through a stack of moist timber is in a downward direction. This is not self-evident. However, calculations show that in the usual kiln operations the combined result of spontaneous cooling and in-

crease in humidity increases the density sufficiently to cause the air to descend. Provision must be made in stacking to comply with this principle. Another principle of equal importance is that the stacked boards should not be placed so as to baffle the air currents, otherwise the moving air will short-circuit the stacks and not pass through them. In the case of movement of air by fans or blowers through a stack of timber, the motion is due to differences in pressures, and between any two portions of the kiln which differ in pressure the air will flow along the path of least resistance. Since the resistance of various portions of the pile must necessarily differ greatly, the velocities of the air will also differ accordingly. In this respect forced draught differs essentially from natural circulation produced by differences in density. Natural circulation is also self-adjusting. Again, unless the draught is invariably in the same direction as the natural tendency, it will operate against it. For these reasons forced draught of itself is not apt to give uniform drying, except when it is properly combined with the natural system. In choosing a kiln the control of the three fundamental conditions, together with the other principles mentioned above, must be carefully considered. It is found that commercial kiln drying failures are usually due to faulty circulation.

Types of Kilns.—There are dozens of kilns on the market. Present practice in kiln drying, in the various parts of the world, varies enormously. Even with the same species of timber and for the same purpose, all kinds of conditions are met with. Temperatures vary anywhere from 70° to over 220° F., and 1-inch timber, requiring from 2 to 30 months' yard seasoning, is kiln dried in from two days to six weeks. Usually hardwoods are dried at a much lower temperature than softwoods. The dry kiln, however, has been one of the most troublesome factors arising from the development of the timber industry. For, unfortunately, until recently proper methods of seasoning have received little scientific attention. Forms of kilns, and mode of operation, have in the past commonly been merely copied by one wood-working firm after the example of some other older establishment. Thus, to put it mildly, present practices have many shortcomings, and methods of drying "difficult to season timbers," such as hardwoods, have often been on wrong lines.

Kilns for drying timber may be divided into two classes, *viz.*:—(i) Progressive, and (ii) Compartment. For convenience in handling, the timber to be dried is usually in trucks on rails. In a Progressive kiln (Fig. 2) the conditions at one end differ from those at the other, and the timber is dried progressively by being moved throughout the whole kiln. The air circulation is longitudinal, so that the conditions during drying vary, more or less uniformly, from one end of the kiln to the other. In Compartment kilns (Figures 3 and 4) the

conditions are changed during the drying process, and the timber remains stationary and is all dried at one time. The air circulation is transverse, so that the conditions at any time during drying are uniform throughout the whole kiln. The methods of operation generally used may be placed under the headings:—

(*a*) Non-condensing,
(*b*) Superheated Steam;
(*c*) Condensing.

In (*a*), the humidity or dampness is controlled by the use of escaping steam and evaporated moisture (Figure 2). The circulation may be either natural or forced, and the moist air is allowed to escape from the kiln. Softwoods and "comparatively easy to season" woods, such as pine, ash and cedar, are usually dried by this method, the kiln being of the progressive (i) class. These kilns, however, are only very roughly under control and may be regarded as not being positive enough for hardwoods, especially if they are "difficult to season."

In (*b*), superheated steam is passed over the timber, either by natural or forced draught, in compartment (ii) class (Figure 3). Obviously, the method may be used only where the species to be dried are not injured by high temperatures, and where quick drying is essential. Many of the softwoods, such as pine and ash, are successfully dried by this process, but the hardwoods, especially the hard dense, such as oak and walnut, are materially injured.

In (*c*), the humidity is controlled by re-circulating the air, which has taken up moisture from the timber, across water pipes or through water sprays (Figure 4). The temperature of the pipes or sprays governs the amount of water that condenses from the air, and thus regulates the humidity of the air when re-heated before being passed over the timber again. The circulation of air may be either natural or forced. These kilns of the compartment (i) class are under proper control, and for this reason it is believed that all kinds of woods, soft and hard, including the Eucalypts, may be successfully dried by this condensing method.

It appears, then, from the kiln three fundamental conditions analysis that the kiln for drying the hitherto "difficult to dry" Eucalypt hardwoods should be the condensing compartment type. Experimental kilns of this type, using the Tiemann water spray principle, were designed and erected at Millars' Nash Street yard and at the Department of Mining and Engineering, University, Crawley, the kiln at the latter being of Commercial full size cross section. The results of investigations on local hardwood have fully justified the original belief, namely, that the Condensing Compartment method was the solution to

the seasoning difficulty. The kiln at Crawley, as stated before, is of the Condensing Compartment type, with natural and partly forced circulation. The main feature is the humidity control by means of water sprays introduced by H. D. Tiemann, of the U.S. Forestry Service.

Condensing Compartment Kiln (*Tiemann principle*).—Briefly, the kiln (see Figure 5) consists of a drying chamber *A* containing two lines of trucks *T* carrying the timber to be dried, with a partition on either side running the whole length of kiln, making two narrow side chambers *B*, open top and bottom. The steam heating pipes *C*, and pipes *D* for admitting live steam, are placed underneath the material to be dried. At the top of the side chambers *B* are water sprays *E*, at the bottom are gutters *F*, and eliminators or sets of baffle plates *G*, to separate the fine mist from the air. Curtains *H* are hung from the roof to the edges of the stacks, as shown, to prevent the air from passing over the stacks and thus short-circuiting them. The circulation of the air is shown by the arrows. Thus the heated air rises in the flue between the two stacks of timber. As it comes in contact with the stacks, parts of it are cooled and forced to pass outwardly through the stacks to the spray chambers. The movement through the stack is naturally diagonally downwards, and the inclined stacking of the timber ensures that this course is not unduly resisted, otherwise poor circulation is apt to result. In the spray chamber the velocity of the descending column of air is greatly augmented by the sprays. It then passes out through the baffle plates, is heated by the radiators, and commences on its upward course again. Besides inducing an increased circulation, the spray may be said to regulate the humidity. In the side chambers the sprayed air in descending absorbs as much water as it can hold in the form of water vapour. It also becomes misty, for it mixes with small particles of free water. In the zig-zag baffles these particles of water are eliminated and merely saturated air emerges into the main chamber. Evidently the cycle of operations is as follows:—At the bottom of the main chamber the air, at baffle temperature and 100 per cent. humidity, in passing over the heaters, increases in temperature and decreases in percentage humidity. When moving through the timber stack it is gradually cooled through absorbing moisture, and thus continually decreases in temperature and increases in per centage humidity, until, after passing through the spray chambers, it emerges from the baffles into the bottom of the main chamber again with the same baffle temperature and 100 per cent. humidity as before. It is evident, therefore, that the baffle temperature is the dew-point of the air after it becomes heated in passing through the radiators. Knowing the dew-point and maximum temperatures in the kiln, by means of tables, humidity

diagram or psychrometric charts, the minimum humidity of the kiln may be quickly determined at any time. Thus only two stationary thermometers are necessary for determining the humidity and temperature of the air entering the timber, and therefore, for operating the kiln, one in the baffles at *G*, which thus records the dew-point, and the other in the flue *A*, between the stacks of timber, which records the maximum kiln temperature. Neither a wet bulb thermometer nor hygrometer is needed. It is very convenient to use a Thermograph or a recording type of thermometer having long, flexible tubular connection with the bulb, and to have both hands recording on the same dial. The heating coils and sprays to give correct maximum and baffle temperatures, respectively, may be controlled by thermostatic devises. Upper portion of Figure 6 shows a typical automatic installation of maximum temperature control with devices, manufactured by the Powers Regulator Co., U.S.A. The position of the regulator will be noted with regulator valve in the pit controlling the steam supply to the heating coils and governed by the thermostat so located as to be exposed to the kiln temperature. A baffle plate is arranged to cut off the direct influence of the heating coils upon the thermostat.

Usually the used spray water discharges into a well, and by means of a pump ultimately forced through the sprays again.

Lower portion of Figure 6 shows a typical Thermostatic water mixer which automatically supplies water of proper temperature to the sprays and condenser coils. The wells, *F* and *G*, are provided for the source of warm water and hot water, respectively. The well *F* receives its supply from the spray, and condenser coil returns. Well *G* may be supplied by the return water from the heating coils, and also with high pressure steam, which is controlled by a thermostatic regulator, so that a maximum temperature of, say, 180° F. is automatically maintained. The two wells are provided in order to economise in the use of both the cold water and the steam required in the operation of the sprays, and condenser coils, and so long as the temperature of the spray water is required to be lower than naturally exists in the warm well, the three-way valves are turned in such a way that the thermostatic water mixer receives its two supplies from the cold water line and the warm well respectively. When, however, the spray water is desired at a temperature above that of the warm well, the three-way valves are reversed, so that the mixer is supplied on its cold side by the warm water, and on its hot side by the hot water from well *G*.

Construction.—It is not intended to offer here working plans or specifications of the kiln, but merely to give a sufficient description to make its construction plain. The drying kiln at

Crawley, which is of the proper commercial section, is always available for inspection, and plans of the kiln may be seen either at the Department of Mining and Engineering, University, Crawley, or at the office of the Conservator of Forests, Perth. At Crawley kiln (Figs. 5 and 7), for convenience in loading and unloading, the rails are arranged to be at ground level. Below ground the outside walls of the kiln are of brick in cement, the floor being of concrete. On the top of the walls, and thus above the ground, rests a simple framed wooden construction. Over all this is a shingle roof to keep out the weather and prevent excessive radiation. The kiln should be more or less airtight, and the inside of the kiln must be made waterproof. A certain amount of radiation from the side walls is desirable, since it increases the efficiency of the condensing system, the sprays, for the heat given to the walls does not need to be removed by the sprays. It is necessary, however, to insulate the top of the kiln—sawdust is quite satisfactory—in order to prevent condensation and drip on the timber piles. The vertical faces of the spray chambers must be both air and water-tight. The baffles are made up of boards in convenient sections. They should fit tightly, as any leakages will allow the spray to get through to the steam radiator pipes, which would spoil the humidity regulation. The water sprays consist of small brass nozzles of the easily cleaned and adjustable "demorel" type, which will deliver about 3 lbs. of water per minute at about 40 lbs. pressure. They should give a spray of water, and not a mist. The water pipes should be arranged so that it is easy for them to be inspected and cleaned. Galvanised pipes must not be used in the kiln. The steam radiators are constructed with 1-inch wrought iron pipes. The whole of the woodwork and iron inside the kiln should be coated with a good high temperature asphaltum varnish or P. & B. paint.

Operation of the Kiln.—At the commencement of operations the timber must be heated through before any drying takes place. It is thus usual to steam the timber at a temperature of about 120° F. for a few hours (see Appendix I). The steaming is also useful in removing any initial or residual case-hardening before beginning drying. Briefly, the minimum per centage humidity of the circulating air is governed by the per centage moisture content of the stacked timber (see Appendix I). From green to fibre saturation point (30 per cent.) the humidity must be high, from 85 per cent. to 75 per cent., never less, while it appears the maximum kiln temperature, with jarrah, is about 115° F., say (see Appendix I). After this point has been passed, the per centage humidity may be gradually decreased until it reaches about 40 per cent. at end of drying operation, the temperature also during this period being gradually increased, reaching a maximum of 140° F., say. The

per centage moisture content of the stack must evidently be obtained from time to time. Accordingly, sample boards are placed in the kiln and these are weighed, from time to time, and their per centage moisture content determined (see Appendix III). It is also necessary to take, from time to time, prong sections of material in the kiln in order to control the rapidity of the drying and casehardening. If excessive casehardening is taking place it may be quickly removed by restoring surface plasticity, that is by subjecting the timber to a warm saturated atmosphere, usually steam, for a few hours. The behaviour of sections of 1-inch boards pronged during the various stages of the drying is shown in Figure 8, and needs no further explanation. Conversely, these sections may clearly be used to roughly indicate the moisture content. The timber may be considered thoroughly kiln dried if moisture content is about 8 per cent. Provisional instructions for drying jarrah are given in Appendix III.

Additional Difficulties in Operation.—Difficulties in operation, apart from those already mentioned, are due to the fact that the stacked material, which is being evenly dried in the kiln, has naturally considerable variations in (i) moisture content, (ii) density. Thus some pieces may contain 75 per cent. and others 40 per cent. moisture, while the density may vary between 37 and 52 lbs. per cubic foot when dry.* It appears to be necessary, in order to be on the safe side, to subject the "mixed" material to comparative mild drying conditions.

Results of Tests.—Plate 1 shows the particulars, arranged graphically, of a typical kiln drying operation. Figure 9 shows drying curves, respectively, for 1 in., 3 in., and 4 in. thickness jarrah, which was uninjured in seasoning. Roughly, using the information now available, the rate of drying jarrah, from fairly green to 10 per cent. moisture content, without injury, and the conditions being mild, is as follows:—½ in. stuff, 7 to 10 days; 1 in. stuff, 4 to 5 weeks; 3 in .stuff, 3 months; 4 in. stuff, 4 months. It may also be noted that it appears to be desirable to kiln dry the jarrah as soon as possible after cutting, for end checking soon takes place in the air. This is contrary to American practice with hardwoods, which are air dried for six months, or over, before placing in kiln.

Appendix I.

Results of Experiments.—Investigations on the behaviour of jarrah in drying are by no means complete. Sufficient information, however, has been obtained for a rational understanding of the causes and prevention of injuries. The following physical properties of jarrah (which are more or

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* See W.A. University Timber Tests, 1917.

less similar in other woods*) when drying have been established:—

1. (*a*) Shrinkage begins when green, with a moisture content of 70 per cent., say, and continues until dry. From green to the fibre saturation point shrinking proceeds at an even rate, and afterwards at an increased uniform rate (about two-fold). It is believed that the contraction at first is due to a form of collapse of the cells, and afterwards to the "true" shrinkage of the cell walls. (See Appendix II.)

   (*b*) The moisture content reckoned on dry weight is about 30 per cent. at the fibre saturation point. (See Appendix II.)

2. (*a*) Rate of transfusion of moisture through the wood is slow compared, say, with the softwoods.

   (*b*) Moisture tends to transfuse from the hot towards the cold portion of the wood.

3. (a) Is plastic while hot and moist and becomes "set" in whatever shape it dries.

   (*b*) Is excessively soft and plastic under moist conditions when temperature is as low as, say, 150° F.

4. Shrinks less in a damp atmosphere, when dried rapidly than when dried slowly.

Injuries, and Prevention in Seasoning.—From the foregoing facts the troubles and remedies in drying will be readily understood, some of which are dealt with below.

Cause of Checking.—Checking results from Item 1 (*a*), that is, unequal shrinkage. In drying jarrah, the necessarily drier outer shell tends to shrink or contract more than the wet inner core. The latter prevents it from doing so, and this straining action sets up stresses, owing to differential drying. The outer shell is evidently in a state of tension and the interior in compression, as shown in Figure 10, Diagram B. If the contraction is comparatively great these resulting stresses will exceed the strength of the timber across the grain, which will be torn apart on the outside in checks, as in Diagram A, and the material will be relieved of stress.

Cause of Casehardening and its evils.—Casehardening results from Items 1 (*a*) and (*b*), 3 (*a*), and 4, and occurs when the surface of the wood becomes 'set" (*i.e.*, below the fibre saturation point) in a partially dry condition, while the interior is still wet. This condition is due to too rapid surface drying,

* See "Kiln Drying of Lumber," by H. D. Tiemann.

i.e., the evaporation from the surface exceeds the rate at which the water in the centre transfuses outwardly. If the interior of the casehardened piece of wood dries further it tends to shrink, while the "set" condition of the surface, or outer shell, tends to prevent it from doing so. As a result of this, together with Item 4, *viz.*, "that the slower wood dries the greater the shrinkage," the strains, and consequently the stresses set up, are the reverse of those already considered. For now the outer shell is in compression and the interior in tension as shown in Diagram F (Fig. 10). If these stresses exceed the strength of the timber, portions of the interior of the timber will rupture and splits will appear, as in Diagram E. This internal checking is usually called honeycombing. It has been seen that excessive casehardening ends in checking and honeycombing. Since disaster will take place in seasoning unless casehardening is controlled, it is evidently a very important factor.

Prong Tests for Casehardening.—Simple tests, as under, may be used before the wood, of course, is permanently injured, for indicating the casehardening, if any. Discs, or narrow cross sections, say 1 inch thickness, are sawed across the piece of wood to be tested. These are immediately slotted according to Diagram H (Fig. 10) by running, if possible, five parallel saw cuts nearly through, and breaking away two of the tongues thus formed—namely, the second and fifth. If the prongs at once show no tendency to bend outwardly or spring inwardly, as in Diagrams C or G, respectively, but remain normal, as at H, there is little or no casehardening, for the material must be in an unstrained condition and thus free from shrinkage stresses. If the outer prongs at once bend outwardly, as in Diagram (C), then the outside is dried than the inside and the piece is in a first stage condition leading to casehardening, with its tendency to check. If (C) is now dried in a warm room, the prongs wll finally bend inwardly, and remain so permanently. The outer prongs will all spring inwardly, as in Diagram G, if the outside has "set," that is, if in the final stage of casehardening, with its tendency to honeycomb. In the above the stress Diagrams B and F readily explain the action of the prongs.

Prevention of Checking.—Evidently, outside checking due to excessive surface drying may be prevented by properly adjusting the humidity of the air and so controlling the surface evaporation. It has been found that the moisture content of the wood determines, to some extent, the allowable or minimum safe working per centage humidity of the circulating air. Thus, if per centage moisture content of wood is high, the per centage humidity of the air must be high. Green or high moisture content jarrah can only be successfully dried at first in a damp atmosphere, say, 85 per cent. humidity. Again, with 1 inch boards during almost the whole of the drying operations it

appears to be undesirable for the humidity to be less than 75 per cent. It should be noted that the rate of surface evaporation should not be controlled by reducing the air circulation, since a large circulation is needed at all times to supply the necessary heat.

Prevention of Casehardening and Honeycombing.—Honeycombing, obviously, may be eliminated by preventing undue casehardening. If casehardened, the material would be in a stressed condition, as in Diagram F (Fig. 10), and a little thought should suggest a means by which it may be removed. Clearly, if the hard outside shell were softened, the "outside set" and resulting strains (as in Diagram F) would vanish and the piece relieved of stress. Experiments (Item 3*b*) showed that thoroughly moist warm air caused the wood to become soft and plastic, and thus remove casehardening. In the kiln (Figure 5), steam pipes *D* with perforations are provided to admit live steam, which will maintain a thoroughly wet atmosphere, and even with a comparatively low maximum temperature of 140° F. the casehardening will be entirely eliminated in a few hours, provided it has not gone to the extent of causing honeycombing.

Prong Tests for Removal of Casehardening.—Casehardening material when pronged, as explained before, will assume the form shown in Diagram G (Fig. 10). If after steaming another pronged section of the material remains normal, as at *H*, the casehardening has been eliminated and the exposure has been correct. If the steaming process has been carried on too far, a pronged section will take the form shown in Diagram C.

Warping, twisting or cupping is due to internal stresses caused by unequal shrinkage. Casehardening is one cause. It is often due to the warped direction of the grain of the wood, coupled with the fact that the shrinkage is different in different directions. "Curly grain" is very apt to warp, and an "interlocking grain" is even more effective. Another cause is through the expelling of moisture evenly from all parts in which it does not exist evenly. Of course, casehardened boards (Diagram F, Fig. 10), when sawed down the centre, so as to make two boards of half the original thickness, will cup, the original surface becoming convex. Articles then manufactured from casehardened material are apt to warp and give trouble.

Prevention of Warping and Cupping.—In the drying kiln warping and twisting can be prevented to some extent by careful stacking or piling. The distance pieces or "strips" (Fig. 7) are placed at suitable intervals apart in the transverse direction. The weight of the superincumbent timber acting through these strips tends to prevent the twisting of individual boards. The cupping trouble is eliminated by arranging for the surfaces of a board to dry at an equal rate. Even air

circulation in the kiln—sloping stacking and uniform thickness of strips—will ensure even drying of the two faces.

Temperatures for Drying.—Items 1 (*a*), 2 (*a*) and 3 (*b*) indicate clearly that comparatively low temperatures must be used in drying. During the first drying stage up to the fibre saturation point the humidity is high and so the kiln maximum temperature must not approach 3 (*b*), *i.e.*, 150° F. High temperatures and the expulsion of free water at too rapid a rate will also produce collapse of the cell walls and disaster. By arranging for the baffle temperature to be between 100° F. to 120° F., the maximum temperatures necessary to preserve the required humidity are not unduly high. During most of the experiments at Crawley the baffle or dew-point temperature has been 100° F., a temperature easily maintained throughout the whole year, and the maximum kiln temperature has seldom been above 135° F.

Precaution at Commencement of Operations.—Item 2 (*b*) indicates that the timber should be heated through before drying begins. A simple experiment shows that if wood is heated on one side and cooled on the other that the moisture, or water, will be driven from the heated to the cold side. Evidently, in the kiln, heat should penetrate into the interior of the timber before drying begins. At the commencement of the kiln operation then the air must be saturated with moisture, and so live steam is frequently used, both to heat up the wood and provide also for a 100 per cent. humidity. Also from Item 2 (*b*) results a quick and useful test to determine whether a piece of wood from kiln is dry. While still hot, a freshly sawed end grain surface of the wood is placed on a cold piece of iron. The moisture, if any, in the wood will be quickly condensed on the cold metal.

Appendix II.

The Fibre Saturation Point in Jarrah.—In wood the water may exist in two conditions, *viz.*, as free water contained in the cell cavities, and as hygroscopic or fibre moisture absorbed in the cell walls. In wet and green woods the water exists in both conditions, the free water usually having no particular effect upon physical properties such as shrinkage or strength. In determining the moisture content, both the free water and the absorbed are necessarily included. Consequently, in drying out a piece of wet wood, since the free water must evidently evaporate before the absorbed moisture in the cell walls can begin to dry out, there will be a period, providing, as is usual, that shrinkage does not take place, during which the strength remains constant, although varying degrees of moisture are indicated. But just as soon as the free water has disappeared and the cell walls begin to dry, the strength will begin to

increase. This point is called the "fibre saturation point." Nearly all woods do not shrink until this fibre saturation point is reached, and with these, referring to their moisture-strength diagrams, the fibre saturation point will easily be recognised as the part where the steep curved portion is intersected by the straight line parallel to the moisture content axis (Plate III). It is usually between 25 per cent. to 30 per cent. moisture content. The fibre saturation point may evidently be determined by obtaining the moisture content when either shrinkage first takes place or an increase in strength takes place. However, in drying jarrah and other Eucalypts, shrinkage takes place well before the 25 per cent. to 30 per cent. moisture content—even when green. Again, the strength also increases almost from the beginning of the drying, so that the point cannot apparently be obtained by the usual methods stated above.

Shrinkage Analysis.—Plate I gives graphically typical drying particulars of jarrah tagentially cut specimens, and Plate II shows the relation between the per centage moisture content and the per centage shrinkage in the width (reckoned on dry dimension at 10 per cent. moisture). It is seen that the observed results may be assumed to lie on pairs of intersecting straight lines, and evidently these intersection points will be near the fibre saturation point. The "rounding" near the intersection points was anticipated, for it is due to the fact that the critical change can only take place gradually through the thickness of the specimen. The full line is an average shrinking curve, the fibre saturation point being 30 per cent. Roughly, the shrinkage in the tangential direction from the fibre saturation point (30 per cent.) to dry (10 per cent.) is 4 per cent., based on dry (10 per cent.) dimension; between 70 per cent. and 30 per cent. moisture content the shrinkage is 3 per cent., making a total of 7 per cent. from green (70 per cent.) to dry (10 per cent.). Usually with "true" shrinkage (*i.e.*, due to contraction of cell walls) the tangential shrinkage is twice the radial, so that the radial shrinkage should be about 4 per cent. ÷ 2 or 2 per cent. between fibre saturation point and dry. Experiment shows that the radial shrinkage from green to dry is about 5 per cent. (reckoned on dry dimensions), so that the radial shrinkage between green (70 per cent.) and fibre saturation point (30 per cent.) is about 5 per cent. — 2 per cent. = 3 per cent., which corresponds with the per centage shrinkage in the tangential direction. It appears from this result that the initial shrinkage (*i.e.*, up to fibre saturation point) is due to the wood cells, which are roughly circular, contracting as the free water is removed and thus diminishing equally in all directions. In other words, evidently, the cells are plastic and pliable when moist, and much free moisture

causes them to distend, while the removal of water causes the cells to become more or less deflated, and perhaps collapse. Micro-examination is necessary in order to fix this idea. After the fibre saturation point is reached the cell walls begin to shrink and break up in a similar manner to all other timbers. An analysis of the shrinkage then from these experiments fixes the saturation point at about 30 per cent.

Strength Analysis.—The moisture bending strength diagrams for jarrah shown in handbook of W.A. Government Timber Tests, 1906, by Mr. Julius, are smooth curves. Plate III shows curve, Jarrah No. 1, taken from the above-mentioned handbook, and also curves for pine and chestnut, respectively, which are typical of most timbers. Consideration showed that the absence of a horizontal line and a definite kink in the jarrah curves might be due to (i) the specimens tested being more or less casehardened, or (ii) the early shrinking not being due to true cell wall shrinkage. Cause (i) was difficult to deal with now, and moreover, if considerable, would have been detected when the tests were made in 1906. Further analysis in cause (ii) showed that this was likely to lead to a rational explanation of the peculiar irregularity in the jarrah curves. Accordingly, using values obtained from the moisture-strength curve for jarrah, referred to above (Plate II), the strength of the timber was calculated on the basis that no shrinkage in drying takes place at all. In other words, average shrinking values were taken and the strength calculated on the assumed original green section, and not on the actual section at breaking as given, of course, in the curves of Mr. Julius. Plate IV gives particulars of the analysis necessary in order to compute the two-fold effect of the alterations in dimensions of cross section, on the "bending rupture strength," due to the changes (i) in the section modulus, and (ii) in the density. The probable green dimensions of specimens having known dimensions when moisture content $=M$, computed from average curve, Plate B, are given in upper portion of columns. Since there is a kink in the "shrinkage" curve (*i.e.*, two intersecting straight lines) it will be necessary to have two separate sets of equations depending, of course, on the per centage moisture content. The alteration in the modulus of section due to shrinkage is shown, as well as the ratio of probable rupture bending stress on section when green (70 per cent., say) to actual stress on section at rupture (M per cent.). Evidently S, green, $= A \times Sm$. Knowing M and obtaining Sm from curve (Jarrah No. 1), the value of the right-hand portion of this equation can easily be computed, and so S, green, obtained. Thus, $M = 40$ per cent.; $B = .9325$; from curve S at 40 per cent., Moisture $= 12{,}000$ lbs. sq. inch; then S, green, $= A \times Sm = .9325 \times 12{,}000 = 11{,}200$ lbs. sq. inch. Plate III, Curve (Jarrah No. 2) shows the result of plotting

obtained by this analysis. The alteration in the density (apart from the water) and the probable effect on strength is given in third row, and explains itself. Since (i) and (ii), above, may act jointly, it is necessary to consider their joint effect on the strength, and this is done in row No. 4. Thus, if $M = 60$: $Y = .963$: from curve S at 60 per cent. moisture = 11,400 lbs.; S, green, $= Y \times Sm = .963 \times 11{,}400 = 11{,}000$ lbs. Plate III, Curve (Jarrah No. 3) shows the result of graphing the above joint effect. These curves (Jarrah Nos. 2 and 3) are similar in form to those of other timbers, and clearly show that if no shrinkage took place in jarrah in drying from green to a 30 per cent. moisture content condition, the "strength" would be constant, and from 30 per cent. moisture content to a dry condition an increase in "strength" takes place, apart from the no shrinking effect. Evidently, the 30 per cent. moisture content is about the fibre saturation point. It will be found that varying the shrinkage values (7 per cent. and 5 per cent.), within reason, has little effect on the value (30 per cent.) of the saturation point.

Appendix III.

Provisional Instructions for Drying Jarrah.

General.—After being sawn, the material should be "picked" free from defects, carefully stacked and protected from the sun and wind, in covered sheds, and kiln dried as soon as possible, when green.

Stacking or Piling.—Timber must be evenly stacked or piled and held flat and straight while drying. Contact between wood and strips or distance pieces should in no case exceed 1½ inches in a direction lengthwise of the stack. Strips varying in thickness from one inch to two inches should be used for timbers of thicknesses of one inch to four inches, respectively. Timber should be so arranged in the stack that drying will take place equally from both surfaces in planks, and from opposite faces in squares. The timber must be so disposed in the dry kiln as to permit of easy access on both sides of the stack.

Preparation of Samples, etc.—Representative samples must be inserted in the stack, to be kiln-dried in such a manner that they will be subjected to the same drying conditions as that portion of the stack where inserted, and so that they can be removed for periodical weighing in order that their moisture contents and, therefore, the mean moisture content of the stacks can be known at all times. Allow three samples for each 5,000 board feet or less of material. The samples should be at least 2 feet long and should not be cut nearer than 2 feet from the end of one of the pieces to be dried. The samples should be carefully weighed at least daily where the time of drying is ten days or less, and at least every other day for longer periods. They should be placed in a stack and distributed so as to be

exposed to average, most rapid, and slowest drying conditions, except that they should not be placed on the top layer or bottom layer, and the temperature and humidity should be regulated according to the samples placed in the warmest part of the stack. The per centage moisture content of the sample should be determined by cutting sections 1 inch thick from both ends at the time the sample is sawed from the piece. These, after being weighed, are thoroughly dried and again weighed, the difference in the weights being due to evaporation of moisture, and the percentage original moisture reckoned on the dry weight is easily computed. The ends of the sample are to be given a thorough coating of asphaltum varnish mixed with lampblack, to prevent end drying, before placing them in the stack. After the dry weight of the sample has been determined, the average moisture condition of the pile during drying can be found by weighing the samples and calculating the condition of the stack from their weights.

Example:—

Original weight of sample, 8.65 lbs.

Original moisture percentage (average of the two discs), 73.

Calculated dry weight of sample, 8.65 ÷ 1.73 = 5.00 lbs.

Current weight, 6.18 lbs.

Moisture in sample, 6.18 — 5.00 = 1.18 lbs.

Current moisture percentage 1.18 ÷ 5.00 × 100 = 23.6 per cent.

In this manner a record must be kept of the percentage of moisture in the timber in the kiln. A standard test should be made on each sample before the timber be removed from the kiln.

Instruments.—Thermometers: At least one recording thermometer of approved make must be used in each dry kiln. This must be checked daily with a standard thermometer or a glass thermometer that has been calibrated to an accuracy of 1° F. and placed in such a position as to record the maximum temperature to any portion of the stack. All glass thermometers should be accurate to 1° F. Thermometer bulbs must be shielded from direct radiation of steam pipes or wet timber, cold walls or surfaces, and receive a free circulation of air.

Steaming.—Admit sufficient steam to saturate the air, at the stated temperature, as follows:—

(i) At the beginning of the drying operation, with green wood, six hours for each inch of thickness, at a temperature not over 120°. With previously air-dried wood, eight hours for each inch in thickness.

(ii) Near the end of the drying, in order to eliminate internal stresses (casehardening) at a temperature not to exceed 140° F. and for a time not to exceed three hours.

Temperature and Humidity.—Average or mild conditions are here specified. Lower temperatures and higher humidities are permissible. In no portion of the stack should the average operating temperature exceed, or the average operating humidity fall below, nor should any piece of wood be subjected to more severe average operating conditions than the figures given in the table below. However, an accidental rise in the temperature and decrase in humidity will not damage the timber, providing the period of time is less than than two hours, and during which the rise in temperature does not exceed the average specified temperature by more than 10° F., nor the humidity be more than 10 per cent. less than the average specified humidity. Furthermore, the progression from one specified stage to the next must proceed along *uniform* lines.

Maximum Average Drying Conditions.

Stage of Drying.	Maximum Temperature °F.	Approximate Relative Humidity Percentage.	Baffle Temperature °F.
At the beginning	110°	85	105° F.
After fibre saturation is passed (30 per cent.)	115°	75	105° F.
At 20 per cent. moisture ..	120°	65	105° F.
At 15 per cent. moisture ..	130°	50	105° F.
At 12 per cent. moisture ..	135°	45	105° F.
At 8 per cent. moisture	140°	40	105° F.
Final	140°	40	105° F.

[More severe drying conditions can be used (*i.e.*, commencing with 115° F. baffle temperature) without visible injury of any kind, but on account of injury to strength and introduction of internal stresses, through the varying density and moisture contents of the pieces, the milder conditions are (provisionally) specified.]

Tests of Material after Drying.—At the end of the run, standard tests must be made for moisture content and casehardening. Material for these tests should be taken from each of the samples in the stacks and from other pieces, which should be representative of the dried stock, at least three pieces for every 5,000 feet or less, and taken from different parts of the kiln. Two adjacent sections, 1 inch thick, should be cut from the centres of each of the samples and pieces of stock. Due precaution must be taken to prevent moisture evaporation between the time of sawing and the time of weighing these sections. The first

section should be dried and the moisture content obtained by the standard method previously referred to. The other section, if cut from a 3-inch plank, should be slit in the longest direction, parallel to the faces of the piece, into six equal tongues or prongs, leaving about $\frac{3}{4}$ inch solid wood joining the prongs at one end of the section. The second prongs from both sides are to be broken out, leaving two outer prongs and two in the middle (see Figure 10). The curving of these prongs indicates the degree of casehardening. If the prongs remain straight in indicates perfect conditions as to the stress and moisture. If the outer prongs bend in, it means that the piece was casehardened. If they bend out, it means that the piece was oversteamed in final steaming. If the centre tongues first bend outwardly and finally inwardly, it shows that the centre was not thoroughly dry. For material less than 2 inches thick three tongues should be sawed instead of six, and the inner one removed.

Final Moisture Conditions.—An average dryness of approximately 8 per cent., unless otherwise specified, is required with a variation of individual sticks from not less than 5 per cent. to not more than 11 per cent. Upon removal from the kiln the wood should be allowed to remain in a room with all parts under uniform shop conditions at least three weeks for 3-inch material, and other sizes in proportion, before it is manufactured.

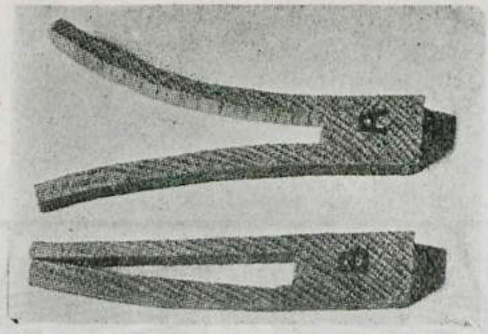


Fig. 1.
Pronged Discs.

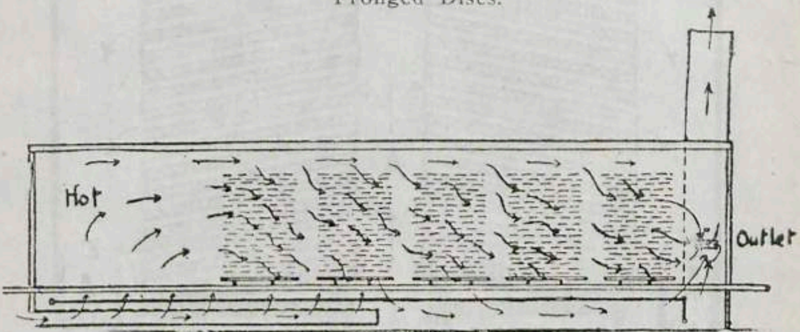


Fig. 2.
Progressive Class (1): (a) Type: Longitudinal section of kiln. Arrows show the direction of the circulation. Timber stacks moved from right to left.

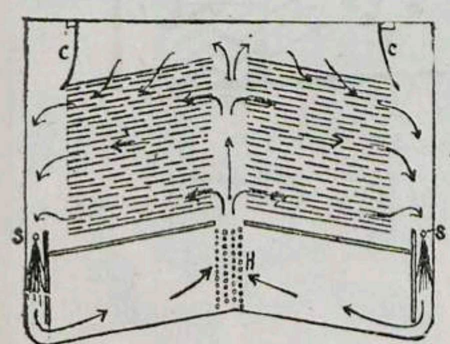


Fig. 3.
Compartment Class (2): (b) Type: Cross section of kiln. Timber stacks remain stationary. S., superheated steam jet; H, heating coils.

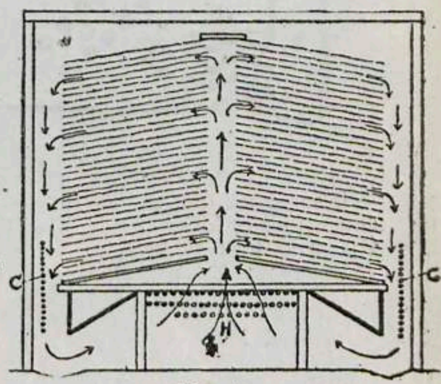


Fig. 4.
Compartment Class (2): (c) Type: Cross section of kiln. Timber stacks remain stationary. C, condensers (or sprays); H, heating coils.

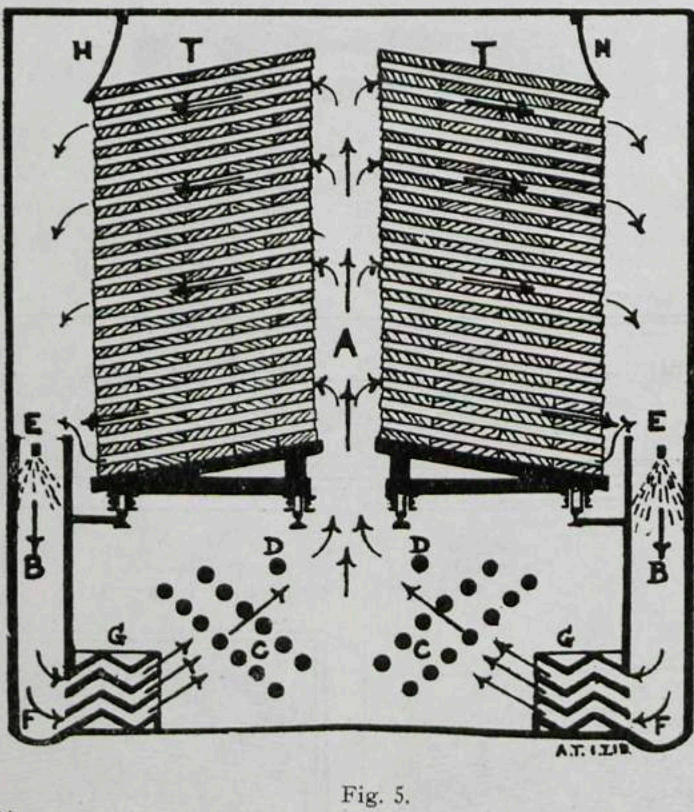
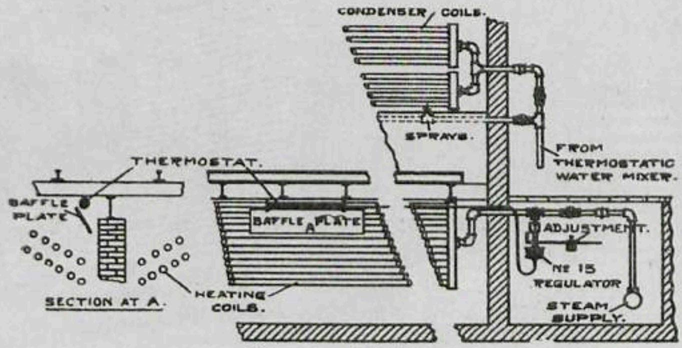
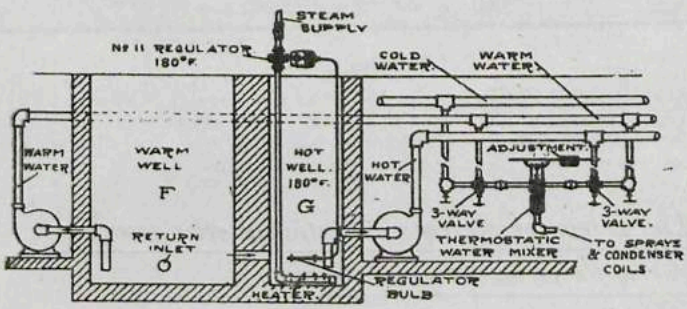


Fig. 5.

Diagrammatic Cross Section of Kiln at University, Crawley. Inside dimensions of kiln: 12 ft. 6 in. wide by 14 ft. 9 in. high. Timber stack: 4 ft. wide by 8 ft. high.



Temperature Control



Water Control

Fig. 6.

Thermostatic Control of Operating Temperatures (Maximum and Baffle).

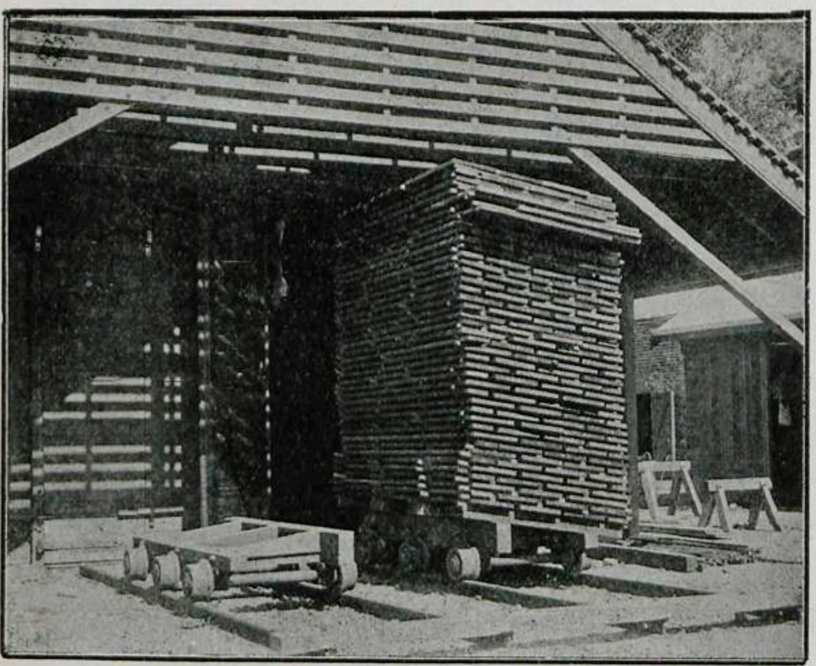


Fig. 7.

Back View of Experimental Kiln at University, Crawley, showing charge of 12 in. by 1 in. and 6 in. by 1 in. Jarrah resting on truck. The slope of the 8 ft. by 4 ft. timber stack is 1 in 7. The transverse distance pieces are 1 in. by 1 in. Jarrah strips.

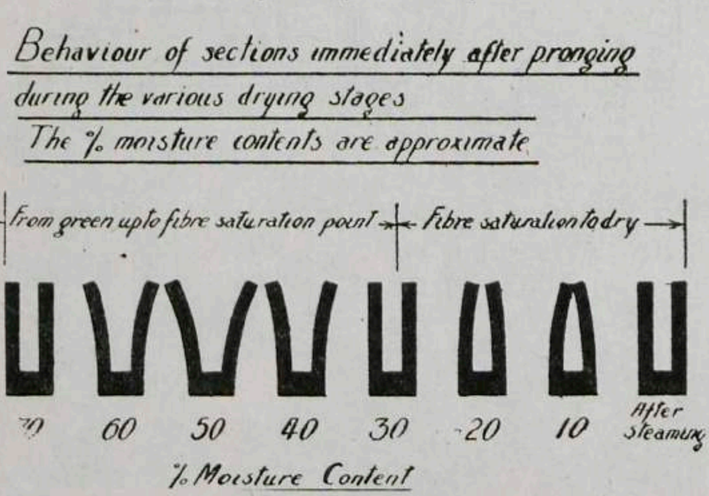


Fig. 8.

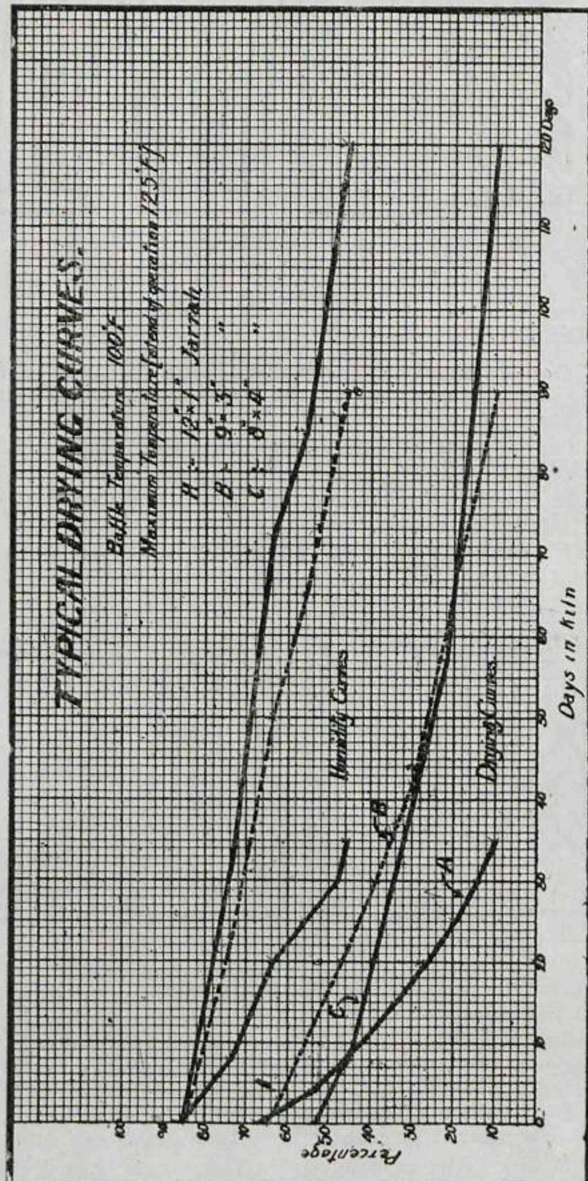

TYPICAL DRYING CURVES.
Humidity Curves
Drying Curves
Days in kiln
Percentage

Fig. 9.

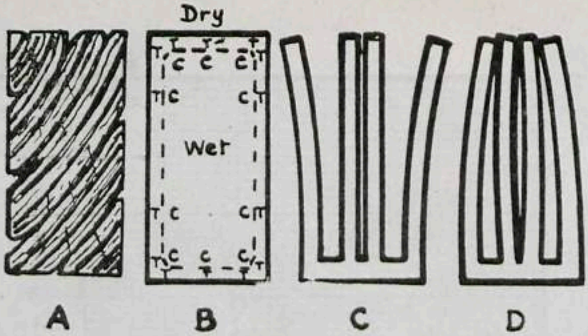


Fig. 10.

OUTSIDE CHECKING.

(A) Outside checking (permanent) due to rapid surface drying, and the strength of the wood being insufficient to resist the internal stresses.

(B) Outer shell, T, drier than interior, C. T = Tension, C = Compression.

(C) If disc (B) be pronged, by 5 saw cuts, it will at once spring into this shape.

(D) If prong (C) be dried thoroughly it will assume permanently the form (D).

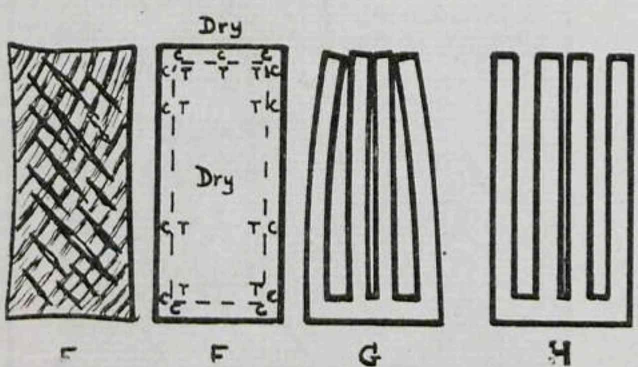


Fig. 10 (continued).

INSIDE CHECKING.

(E) Internal checking or honeycombing (permanent), after wood has more or less completely dried, due to strength of wood being insufficient to resist the internal stresses.

(F) Outer shell, C, below the fibre saturation point, and "set." Permanent stresses. T = Tension, C = Compression.

(G) If disc (F) be pronged, by 5 saw cuts, it will bind the saw and immediately spring into this shape.

(H) Disc pronged and without casehardening. If (F) be steamed and stresses neutralised or removed, thereby a pronged disc will assume the form (H). If steamed too much a pronged disc will spring into the shape (C).

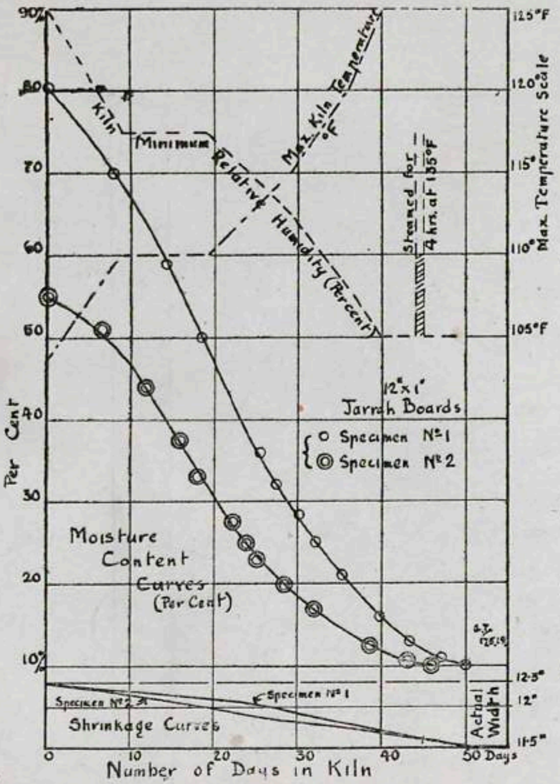


Plate I.

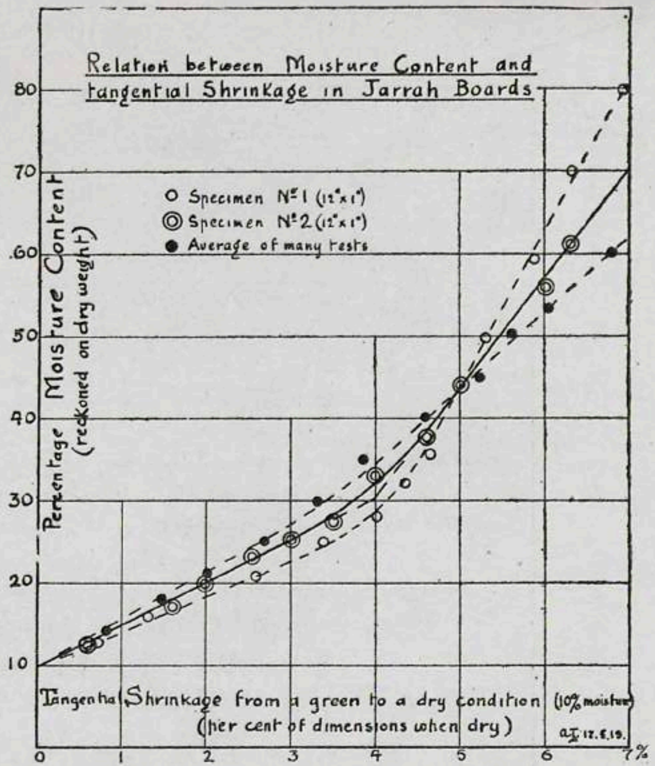


Plate II.

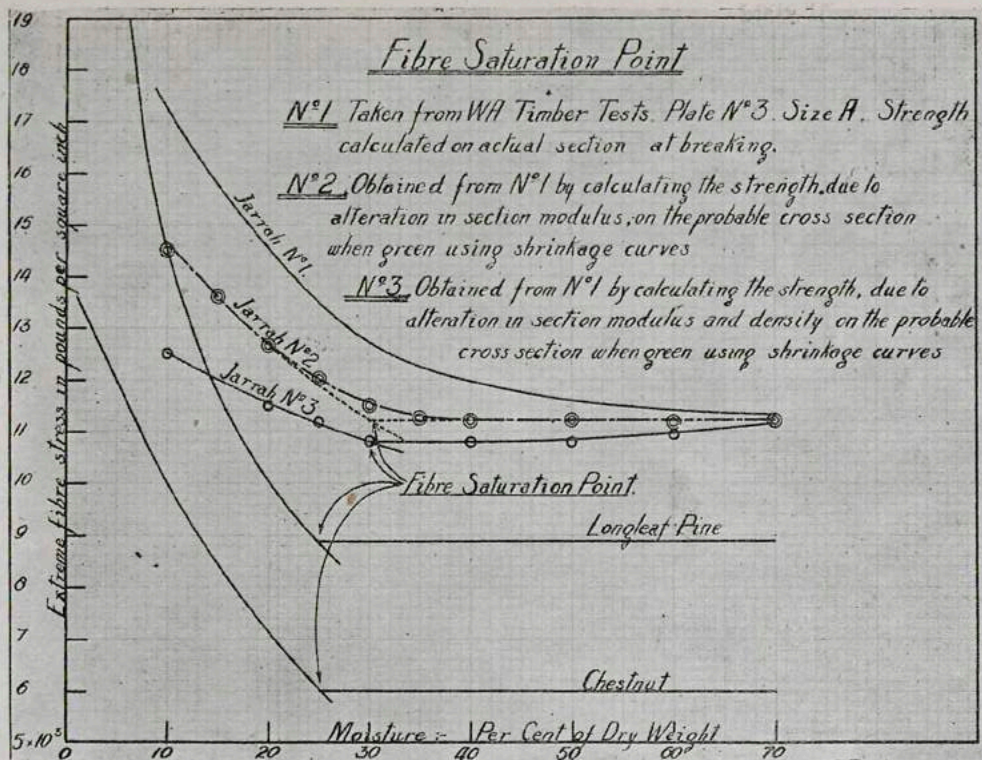

Fibre Saturation Point
N°1 Taken from WA Timber Tests. Plate N°3. Size A. Strength calculated on actual section at breaking.
N°2 Obtained from N°1 by calculating the strength, due to alteration in section modulus, on the probable cross section when green using shrinkage curves
N°3 Obtained from N°1 by calculating the strength, due to alteration in section modulus and density on the probable cross section when green using shrinkage curves
Jarrah N°1.
Jarrah N°2
Jarrah N°3
Fibre Saturation Point.
Longleaf Pine
Chestnut
Extreme fibre stress in pounds per square inch
Moisture :- Per Cent of Dry Weight
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5×10³
0
10
20
30
40
50
60
70

Plate III.

Fibre Saturation Point Analysis.

b and d are dimensions of beam when dry (10% moisture Content)
M = % Moisture Content. S_{green} = max. rupture bending stress when green (70%).
$\alpha = \frac{M-10}{500}$: $\beta = \frac{M-30}{1333}$ S_M = —ditto— moisture content M.

Particulars	Percentage Moisture Content	
	$M > 10 < 30$	$M > 30 < 70$
Probable dimensions at M, % moisture	$b(1+\alpha)$ $d(1+\alpha/2)$	$b(1+0{\cdot}04+\beta)$ $d(1+{\cdot}04/2+\beta)$
Probable dimensions when green at say, 70% moisture Content.		$b(1+0{\cdot}07)$ $d(1+0{\cdot}05)$
Ratio of probable rupture bending stress on section when green (70%) to actual stress on section at rupture (M%). (i.e. taking shrinkage into account) Stress, $S \propto 1 \div bd^2$	$\frac{S_{green}}{S_M} = \frac{b(1+\alpha)\,d^2(1+\alpha/2)^2}{b(1+{\cdot}07)\,d^2(1+{\cdot}05)^2}$ $= 1+\alpha+\frac{2\alpha}{2}-{\cdot}07-2\times{\cdot}05$, approx $= 0{\cdot}83+2\alpha$ or, $A = 0{\cdot}83+\frac{2}{500}(M-10)$	$\frac{S_{green}}{S_M} = \frac{b(1+{\cdot}04+\beta)\,d^2(1+{\cdot}02+\beta)^2}{b(1+{\cdot}07)\,d^2(1+{\cdot}05)^2}$ $= 1+{\cdot}04+\beta+{\cdot}02\times2+\beta\times2$ $-{\cdot}07-{\cdot}05\times2$, approx. $= 0{\cdot}91+3\beta$ or, $B = 0{\cdot}91+\frac{3}{1{,}333}(M-30)$
Ratio of probable density (apart from water) of green section (70%) to density of actual section at rupture (M%) (i.e. probably 'strength' will vary directly as 'density') Density, $D \propto 1 \div bd$	$\frac{D_{green}}{D_M} = \frac{b(1+\alpha)\,d(1+\alpha/2)}{b(1+{\cdot}07)\,d(1+{\cdot}05)}$ $= 1+\alpha+\frac{\alpha}{2}-{\cdot}07-{\cdot}05$, approx. $= 0{\cdot}88+\frac{3}{2}\alpha$ or $K = 0{\cdot}88+\frac{3}{1{,}000}(M-10)$	$\frac{D_{green}}{D_M} = \frac{b(1+{\cdot}04+\beta)\,d(1+{\cdot}02+\beta)}{b(1+{\cdot}07)\,d(1+{\cdot}05)}$ $= 1+{\cdot}04+\beta+{\cdot}02+\beta$ $-{\cdot}07-{\cdot}05$, approx $= 0{\cdot}94+2\beta$ or $L = 0{\cdot}94+\frac{2}{1{,}333}(M-30)$
Ratio of probable rupture bending stress on section when green (70%) to actual stress on section at rupture (M%), taking the above two effects to act jointly.	$\frac{S_{green}}{S_M} = A \times K$ or, $X = 0{\cdot}64+\frac{7M}{1{,}000}$ approx.	$\frac{S_{green}}{S_M} = B \times L$ or, $Y = 0{\cdot}738+\frac{3{\cdot}75M}{1{,}000}$ approx. A.T. 19.5.19

Plate IV.

SEARCHLIGHTS AND LIGHT PROJECTION.

By Harold Dowson.

Light projection may be defined as the projection of a beam of light to a distance with the objects of—(i) defining a position for navigation purposes, as in lighthouses; (ii) illuminating a roadway or waterway for the purposes of locomotion, as in the case of locomotive and motor headlights, and ship projectors for such places as the Suez Canal; (iii) illuminating distant objects for attack or defence, as in the army and navy; (iv) flood lighting for large open spaces; and (v) cinematograph purposes.

I purpose in this paper to confine myself principally to the electric searchlights used for naval and military purposes, but before proceeding to describe the methods employed in such, I would like to touch briefly upon the units and standards used in the science of illumination.

Much confusion has existed, and still exists, in connection with these units. Up to 1909 each country had a different standard of light, and, unfortunately, the four principal units were all called candles. There were the British, the American, the French, and the German candle. Unless it was specified which candle was meant, the values were problematical, as they all varied. About 1909, however, Great Britain, France and the United States agreed upon an International candle.

The original British standard was a candle made of spermaceti tempered with beeswax, 6 to the lb., each candle to consume 120 grains per hour. Two candles were used together for the test. This is now superseded by the 1 c.p. and 10 c.p. Harcourt pentane lamps. Pentane is distilled from gasoline, and the specific gravity is .62. The French standard was the carcel, a lamp burning colza oil. The standards used in the United States were generally electric carbon lamps.

Another standard of light proposed was that given by 1 square centimetre of platinum at its melting point. In practice, however, the difficulties of carrying out photometric comparisons with htis unit were considerable, and though attempted several times, it was never fully successful.

The German standard is the Hefner lamp. This burns amyl acetate, with a wick and circular flame. Special attention is paid to regulating the height of the flame, which must be 40 m.m. Amyl acetate is distilled from amyl alcohol with sodium acetate, and sulphuric acid, boils at 137° Cent., and has a smell like Jargonelle pears. It is sometimes called pear

oil. Amyl alcohol is the chief constituent of fusel oil obtained during manufacture of potato brandy.

The ratio existing between these standards is:—1 International candle = 1 Pentane candle, British, = 1 Bougie decimale, French, = 1 candle, American, = 1.11 Hefner candle, German, = 0.104 Carcel, French. 1 Hefner candle = 0.90 International candle.

The illumination on an object at a distance is governed by the law of inverse squares. Accepting the candle as the unit of luminous intensity, the unit of illumination is the candle foot. One candle will illuminate a surface at right angles to it at the distance of one foot with one foot candle. At other distances the illumination produced at right angles is $\frac{c.p.}{d^2}$ Thus 16 c.p. will give one foot candle at 4 feet distance.

The Lux has also been much used as an unit of illumination, specially in Germany. It equals 0.0929 foot candle.

The unit of luminous flux is the Lumen, and is largely used in the United States. With its derivatives, the Phot and the Lambert, it does not seem to catch on in England, as pointed out by Mr. Trotter, president of the Illumination Society. There is still a controversy as to whether it is to be considered as a fundamental unit, or not. It is convenient for calculating the illumination for an area, but the idea is not so easy to grasp as the candle and candle foot. It is defined as the quantity of light in unit solid angle, and radiated from a source of unit intensity. Unit solid angle is the angular space subtended at the surface of a sphere by an area equal to the radius squared. As the surface of a sphere is equal to 4 r^2, the area is 1 ÷ 4 , or 1/12.5664 of the surface of the sphere.

Consequently a source of light of average intensity of one mean spherical candle power will emit 12.5664 lumens.

In all these calculations it is taken that the source of light is a point source, and the surface illuminated spherical, with source central. If plane surfaces are illuminated the rays striking at right angles are the brightest, the illumination falling off at the ends of the diameter of the beam. If the rays strike any surface obliquely the illumination must be reducted by a factor which is the cosine of the angle made by the incident ray with a perpendicular to that surface. The law that governs reflection is that the angle of reflection always equals the angle of incidence.

A few comparative details of illumination will enable us to grasp these units better. An illumination of 12 lux, approximately 1.1 candle ft., is sufficient to read by, whilst more than 50 lux would tire most eyes unduly. Sunlight has been

estimated as from 5,000 to 10,000 foot candles, and full moonlight at from 0.16 to 0.2 lux (approximately .015 to .019 c. ft.) at the earth surface. In these latitudes, however, monlight is far brighter than the European calculation allows. As low an illumination as 1/10,000th ft. candle, or 1 candle at 100 ft., has been measured. This would practically be equal to darkness visible.

It has been established that the light of the full moon enables a torpedo boat to be seen with sufficient distinctness at 1 kilometre, or say 1,100 yards. To produce equal illumination at 2,000 yards, it would require nearly 600,000 candles.

Allowing for average absorption by atmosphere, the standard military searchlight, 90 c.m., or 36 inches in diameter, would produce 1.1 c. ft. on the object at the same distance, 2,000 yards.

Sources of Light.

Various sources of light have been tried—oil, gas, acetylene, and electric light. Oil has proved very successful in lighthouses, but in searchlights the C.C. arc light is used. Acetylene and electric lights and small glow lamps are used for motor head lights, and the electric arc and a special form of glow lamp for kinema projection. Oil is generally used in head lights of locomotives, though electric light has been employed in the United States.

The chief desiderata for the source of light are:—(1) High intrinsic brilliancy; (2) absence of smoke; (3) absence of heat; (4) as small a source as practicable; (5) ease of control; and (6) as little obscuration by fittings or holders as possible. These requirements are more nearly fulfilled by the horizontal C.C. arc lamp than by any other, though some of the gas filled metallic filament lamps developed for kinema work present very hopeful features.

The object of light projection is to produce a beam of light more or less concentrated, and of a shape best calculated for the work it has to perform. Normally, this beam would be approximately horizontal. In head lights and kinema projection, and in some lighthouses, the beam does not require to be rotated in the horizontal plane, nor altered in the vertical. In some lighthouses, however, the beam must be rotated, whilst in searchlights it must be capable of being both rotated and elevated or depressed. It is as easy to make the projector rotate round the whole 360° horizontal as to rotate partly, but the elevation and depression present some difficulties on account of the movement of the lamp inside. It is very seldom that much depression is required, but a considerable elevation is necessary for anti-aircraft beams, and in such, special arrange-

ments are made to secure the lamp. The accompanying outline (Fig. 1) of a projector shows the shape of the complete apparatus. The reflector is at the back, the lamp inside, and the front is closed either by plain glass or lenses, according to the work it is designed for. With the searchlight concentrated beam, plain glass is used, lenses being employed when it is necessary to alter the shape of or disperse the beam. It is necessary in order to ensure steady burning of the arc, and for the safety of the reflector, which is usually of glass, that draughts be avoided. Although the electric arc does not produce such an intense external heat as oil, the heat inside the barrel becomes very great, and ventilation is provided at the back of the mirror with baffle plates, and similarly by a hood on the top. The barrel is mounted on two legs or standards on trunnions, giving the up and down motion. The legs are bolted to a cast-iron plate with edges turned over like the lid of a tin, and this plate is carried on a central pin in a circular box underneath. The edges of the top are concentric with the bottom part, with sufficient clearance outside to allow the top to rotate on the pin and wheels on the circumference. Teh box underneath is bolted down fast, and is called the raceway. and the current is collected in it by means of brushes on the upper part pressing on circular rings in the bottom. The brushes and rings do not, however, always function well in the collection of the heavy currents used, sometimes up to 400 amperes, and they are now being replaced by flexible leads. In each side of the barrel there is a small door for adjusting the arc carbons, and as to look at the naked arc is to court blindness, four peep-holes, two on each side, above and below, are provided, equipped with red glass superimposed on green.

Lamps.

The oil lamps in use in lighthouses can receive but little mention here. The oil employed is generally colza, and, due to the quantities employed, is often pumped through the burner. Headlights using small glow lamps suffer from the linear dimensions of the filament which affect the reflection adversely, but the focussing type and the large glow lamps now being developed for kinema work are overcoming this difficulty. Several gas filled lamps using over 20 amperes at 100 volts have been brought forward, using concave mirrors at the base of the lamp to concentrate the image, and the following is a description of a very large one:—The filaments are mounted in the form of straight bars, as close together as possible, and their useful effect is increased by the use of concave mirrors behind the filaments, the latter being at the centre of the curvature of the mirror. The mirror can be so adjusted that the image of the filaments completely fills up the interstices

between them. It has been found possible to make lamps taking up to 200 amperes and giving 30,000 to 40,000 hefners. Even 100,000 hefners is considered practicable, the chief trouble being the size of the lamp bulb. Such lamps are worked at about 0.25 watt per hefner. A special process, not disclosed, is necessary for sealing in the leading-in wires.

Electric Arc Lamps.—The A.C. arc lamp is, on account of its light curve, unsuited for the purpose of light projection. Owing to both carbons burning practically flat, the curve is approximately, as shown in Fig. 2, as much upwards as downwards. This can be corrected for vertical arc lamps for downward lighting, by a reflector above, but as both carbons burn equally, both are of the same size, so the bottom carbon obstructs the light more than in the C.C. lamp. In a focussing lamp it would be difficult to feed the carbons if a larger size were employed for the top one. In a C.C. lamp the positive carbon burns faster than the negative, and consequently for equal rates of lineal consumption can be made larger. The positive also burns to a blunt point, in the centre of which there is a depression, called the crater. The negative burns to a point. Practically all the light is given off at the positive crater, which in addition to its own intrinsic brilliancy also reflects such light as proceeds from the negative and the arc itself. The curve of light is shown by the curve (Fig. 3), it being of maximum intensity at about 40° with the horizontal, though different types of arc lamps vary somewhat. Although the C.C. vertical arc gives better results than the A.C. arc, it is obvious that with the vertical type much light would be lost to the reflector. Many devices were tried, including double collection and reflection, and then the inclined arc lamp was brought out (Fig. 4). In this the lamp, instead of being vertical, was inclined at an angle of 45° to 60° to it. Whilst this was an improvement; in that, with the arc opposite the centre of the reflector, the latter was illumined with the rays of maximum brightness, a large proportion of the light was lost. Finally, the horizontal arc lamp was perfected, and holds the premier place up to date. As will be seen from the outline sketch of lamp in projector barrel (Fig. 1), practically the whole of the useful rays are thrown on the reflector. The standard military pattern of horizontal lamp is a focussing lamp, adapted for either hand or automatic feed, and to take various sizes of carbons. It can be worked with proper size carbons from 60 amperes to 200 amperes, with a potential difference across the arc of 60 volts. It weighs a little over 100 lbs. The body is made of brass and is furnished with projecting guides along its length to slide it into the grooves in the bottom of the projector barrel, and to lock it in place. Each carbon carrier is supported on wheels so that it can

move easily in a horizontal direction, and is carried forward and backward by a rack geared to the feeding apparatus. Two sets of coils are provided for regulation—the arc striking coils and the feeding coils. The arc striking coils are a pair of horseshoe magnets, one wound in shunt and one in series. Until the arc is struck there is no current in the series coils, and the shunt coils tend to pull the carbons together. As soon as the carbons touch, however, there is a heavy rush of current through the series coil, which overpowers the shunt coil and separates the carbons, thus striking the arc. With normal current the shunt and series coils balance. The feeding magnet is in shunt to arc and is adjusted to work as soon as the voltage reaches 60 volts across the arc. It operates a pawl on the feeding rod, the armature working on a make, and break like an electric bell. The feeding rod is equipped with a hand wheel on the outside of the lamp body accessible from the rear of the projector. A switch with a lever handle outside the body of lamp is fitted in such a manner that when the handle and feeding rod are pushed in as far as they will go and the rod clamped in the notch of the switch lever handle, the magnets are disconnected and the lamp is in hand feed. Conversely, the switch handle is moved down, and the handle with feeding rod pulled out to put lamp in automatic feed. A switch, regulating resistances in the feed magnet circuit, is also provided. The lamp is always started in hand feed, until the arc and the voltage steady up, when the switch is moved down, rod pulled out, and the feed magnet adjusted till it feeds at 60 volts.

The horizontal lamp was finally adopted in 1894.

Reflectors.

The glass lenses and prisms devised for lighthouses by Fresnel gave excellent results, and it was at first attempted to adapt these for searchlights. It was soon found, however, that a curved reflector behind the light source gave better results. Whilst it was recognised that the correct form for such a reflector was a paraboloid, difficulties of manufacture prevented its use for some time. Spherical reflectors were found to be good, provided that the focal distance was equal to half the radius of the sphere. On increasing the size of the reflector, however, it was found that their focal distance caused spherical aberration, or too great a divergence of the rays, and the beam was not sufficiently concentrated. (Fig. 5.)

Colonel Mangin, of the French Engineers, made a great step in advance when he discovered that a silvered glass reflector with the concave and convex surfaces ground to spherical curves of different radii would correct this spherical aberration. (Fig. 6.) These mirrors gave excellent results, but were very

heavy, and very liable to crack on account of the varying thickness of glass.

Paraboloids in glass were first made by Messrs. Chance, who pressed the glass into shape without grinding it, but finally Messrs. Schuckert developed a process of grinding the parabolic surfaces, and since then paraboloids have been adopted with glass of equal thickness.

Reflectors of metal have been tried, and are still being tried. They stand handling better than glass, do not crack, and a rifle bullet, which would shatter a glass mirror, would only make a small hole in a metal one. Plating with palladium and gold have been tried, but the metal quickly tarnishes, and at its best is inferior to silvered glass. The paraboloid would give an exactly parallel beam if the source of light were a point, but as it is impossible to procure a point source of light, there is always some divergence from parallelism; and the beam becomes a cone. This divergence depends upon the diameter of the source of light and the focal length, as will be seen from the diagram (Fig. 7) giving the conical angle of the reflected beam. If *ac* is the source of light, and *d* the centre of same opposite *b*, the centre of mirror, all rays from *d* are reflected parallel to the axis; but rays from *a* to *b* will be reflected to *c*, and the angle *abc* is the conical angle of the reflected beam. The usual angle for a concentrated beam is from 2° to 3°. The diameter of the beam, therefore, at great distances is considerable. At an angle of $2\frac{1}{2}$ per cent. divergence the diameter of the beam at two miles distance is approximately 160 yards. The formula for finding this is $A = \frac{Rd}{F}$ where A = diameter of beam, R = distance in a straight line, d = diameter of source of light, *viz.*, the crater of the positive carbon, and F = the focal length. In practice the focal length must always be kept constant, but unless the arc is burning very steadily there are always changes in the diameter of the crater, and the beam widens and contracts accordingly. The dispersion of the beam at a distance may at first sight appear a great disadvantage, and to some extent it certainly is so. In the most modern type, of which I will speak later, the area has been reduced to one-fourth. The diameter of the 90 c.m. projector beam, 160 yards, as before noted, at two miles is, however, only such as would cover a small vessel, and again much time would be lost in searching the horizon if the beam were too small. If the beam were perfectly parallel the resultant illumination in its area would be much greater, but it is easy to calculate how long it would take to examine the horizon over an arc of 270° at 5 miles radius with a spot of light 3 ft. in diameter.

In certain cases, such as harbour defence, it is desirable to keep a certain area under continuous illumination. This is done by using a fixed or sentry beam with a wide angle of dispersion, varying according to circumstances from 16° to 45°. The beam is not circular, but fan-shaped, spread out horizontally, so that there is a continuous belt of illumination through which everything would have to pass. This can be done by using a parabolic-elliptical reflector, or by lenses mounted in front of the projector in place of the plain glass used with a concentrated beam. The parabola-ellipse reflectors have the vertical sections parabolic, and the horizontal ones elliptical. In this there are practically two foci, and with the source of light at the focus nearer the reflector the rays cross at the farther one, and spread out beyond. It is evident that the distant illumination with these dispersed beams will be less than with the concentrated one. The formula for radius of action is $Ra = R \times \frac{\sqrt{0.65a}}{B}$ where R = distance with concentrated beam, Ra = distance with disperser, a and B angles of concentrated and dispersed beams, respectively. The illumination will decrease just as the cone of rays increases, so that if the illumination with conical angle of $2\frac{1}{2}°$ on a given object at a given range be taken as the unit, the illumination with a dispersed beam of 16° conical angle will be $\frac{2\frac{1}{2}}{16}$ or 5/32nds.

A special projector is used in the Suez Canal, having two lenses, one the ordinary diverging lens, and the other a dark centre lens, or its equivalent. This is done so that the banks only should be lighted, and approaching vessels not blinded by receiving the direct rays.

Intensification of Reflector.—If we consider the light rays from the arc direct, which are emitted over a solid angle of approximately 90°, it will be readily seen that at great distances they will be spread over an enormous area, and consequently the illumination on any object will be but small. At a distance of two miles the diameter of this area would be four miles, and a very small proportion of the rays would strike on the object. It is the function of the reflector to collect these rays and concentrate them over a smaller area, the smaller the angle of dispersion, the greater the illumination being on the object. This relation is known as the intensification of the reflector, which may be written as $\frac{A^2}{d^2}$, where A is the diameter of reflector, and d diameter of source of light. Taking the 90 c.m. projector, the intensification would vary from 1,500 to 2,500.

Mounting of Reflectors.—The greatest care has to be taken in mounting the silvered glass reflectors to allow for expansion

and to absorb shocks. The mirror is mounted in a ring inside the barrel and is provided with padding and spring clips all around its periphery.

Generators and Engines.—The apparatus employed for the generation of current is very simple. For motor head lights small storage batteries are generally used, and for kinema work motor generators. For searchlight work, however, motor generators are scarcely admissable, as probably the current would be cut off just when most required. Sometimes three or four projectors are supplied from one engine-house, but the low voltage and the heavy currents required render it difficult to transmit to any distance, and recourse is often had to the unit plan, where one engine, one generator, and one projector form an unit.

The main thing sought after is reliability. Commercial efficiency does not come into question at all. The plant has to run, and must run without any argument as to its economy. Consequently, everything is built solidly and strongly. The generator used for a 150 ampere arc will take 400 to 500 amperes as part of its day's work, without any trouble, and fuses are either very generously proportioned or omitted altogether. It is highly important to conceal the engine rooms and projector emplacements, and therefore steam engines have been largely displaced by oil engines.

The apparatus contained in a one-unit engine-room would consist of engine, generator and switchboard containing main switch, ammeter, voltmeter, automatic switch, series resistances, and substitutional resistances. The oil engines used are of two kinds—one, a large horizontal slow-running engine, belted to generator; and the other a vertical high-speed direct-coupled set. Both usually burn kerosene, and the former would run at about 200 revolutions, and the latter 600 to 800. For the 150 amp. arc the slow-running belted set would have a 3-ton flywheel 7 ft. in diameter, using a 10-inch heavy belt—often a leather link one. To prevent slipping, the dynamo pulley is large, generally about 30 inches. The vertical direct-coupled sets are also equipped with a heavy flywheel. Ignition is accomplished by means of lamps and ignition tubes, a special type of lamp with large reservoir burning kerosene at about 10 lbs. pressure. Dynamos are compound wound, giving 80 volts at the terminals, and are very conservatively rated. The usual speed for both belted and direct-coupled generators is 600 r.p.m. The series and substitutional resistances are of the same construction, of coils of iron wire, and furnished with regulating switches. The series resistance is set when working to consume 20 volts, including leads to projector at the normal current of the arc, but the switch is left free to adjust for starting purposes or

in case of a drop of voltage. The substitutional resistance is adjusted to take the normal current of the arc, and is then locked. This latter is controlled by the automatic switch, which is wired up with its coils in the lamp lead, and the switch contacts in substitutional resistance circuit. It consists of an electro magnet which actuates an armature, which makes the connection to the substitutional resistance. When the arc is not working the switch connects the generator to the resistance, so that the normal current is flowing from the generator. As soon as the arc is struck the current passing through the electro-magnet pulls up the armature and breaks circuit through the substitutional resistance. The circuit is then on to the arc through the series resistance. As soon as the arc is broken the armature falls and the circuit is once more through the substitutional resistance. This keeps the load from varying from maximum to zero, with a consequent varying voltage. A similar arrangement is now used in some electric furnaces.

Projector Apparatus.—The projector is generally situated a short distance away from the engine room, and connected thereto by cables, great care being taken to instal these out of harm's way. The switchboard in the emplacement contains a main switch, voltmeter, and amperemeter for the main leads, and where remote control is used with switches for the motors mounted on the projector.

Remote Control.—In all cases the searchlight should be directed by an observer at some distance away, preferably to a flank, as it is not practicable to direct a searchlight from the emplacement itself. The absolute control of the light should be in this person's hands, and as the best method of passing orders leaves a lot to be desired, it is better for him to do the directing with his own hands. This is accomplished by fitting two motors, one for traversing and one for elevating and depressing on the projector itself. These motors are connected up to regulating switches at the observer's station, either direct from the engine room or through relays, or from another source of power. The switches are made with a pointer, and arranged so that the beam follows the pointer: *viz.*, if the pointer moves to the left the beam is traversed left, and so on. They are of dead man handle type, so that when at rest the beam is stationary. The traversing motor is fixed on the projector base, and geared to same, and the elevating and depressing motor is fixed on one of the standards and geared to the barrel through a semi-circular rack to give the tilting motion.

Operation.—When starting up, the generator is run on the resistances until the temperature is raised to normal running heat, as iron wire increases in resistance as the temperature rises. Then the series resistance is adjusted to normal, and if

voltage is correct, the emplacement is advised that all is ready. In the emplacement, the projector having been thoroughly cleaned, lamp carbons fitted, the lamp is pushed well forward in the barrel, with carbons well separated, and the main switch is closed. Lamps are always started in hand feed, so the operator turns the hand wheel till the carbons touch, and then quickly separates them. If the arc is struck satisfactorily the lamp is left to burn in the forward position till the body of projector and reflector is well warmed-up, and then it is slid back into focus and placed in automatic feed. As soon as the lamp is burning satisfactorily, the observer is informed, and he directs that the shutters closing the emplacement be opened, or otherwise. If remote control is in use, the operators have only to watch the carbons, adjust as necessary, and re-carbon as required. If there is no remote control, the operators have to rotate the projector either by pushing it round, or operating the traverse wheel.

The striking of the arc takes a very heavy current As before explained, the engine-room voltage is 80 volts, and the projector voltage 60 volts, so that for 200 ampères the total resistance in circuit, excluding the arc, is only 1/10th ohm. Very heavy currents, therefore, pass at the instant the carbons touch, depending a good deal on the skill and quickness of the operator. The carbons are always shaped up before inserting in the lamp, the positive carbon being hollowed out at the end, and the negative pointed. If the positive forms an irregular crater it is necessary to shape it correctly by turning the negative round and burning it into shape. As a good regular beam depends upon the form and size of the crater in the positive carbon, it is most important to keep the carbons in line—the negative well centred with the positive.

The carbon holders are provided with adjusting screws, giving a tilting and a slewing movement to effect this. The adjustment is done by hand by means of insulated box spanners whilst the arc is burning. The operator opens the side door, and inserts his arm, watching the arc through the peep-hole at the side of the door, whilst he twists the carbons into line. The carbons vary in size, the largest positive being 38 m.m. in diameter, about 1½ inches, and the negatives from 26.5 m.m. to 18 m.m., and ten inches long. The positives are cored, and the negatives solid, and the latter heavily coppered. The matching of the pairs is being continually altered, as it is desirable to use as thin a negative as possible. The 26 m.m. carbon has been replaced by a 20 m.m. one. Carbons have to be carefully picked over, and all cracked, split or flawed ones rejected, as pieces of these are apt to fly off in a practically molten condition, and damage the mirror. Even with the best of carbons the glass reflector gets pitted all over with

tiny holes caused by the rain of white hot carbon dust, and molten copper. This gritty dust covers everything inside and falls through the bottom of the projector barrel, necessitating covers for the gear wheels, etc. Some carbons flame very much and I have seen vivid white flames shooting out sideways five and six inches long. The worst, however, is the hissing or roaring arc, which in the confined space of the emplacement is practically deafening. It is generally accompanied by a short arc, and a corresponding diminution of light. It is supposed to be due to enclosure of oxygen in the crater, and can generally be stopped by stopping the feed and allowing the arc to lengthen.

Arc Deflector.—Unless there were some means of drawing down the arc, it would burn principally at the upper edges of the carbons. A magnet will attract or repel an electric current according to polarity and direction, and advantage is taken of this to make a very simple deflector. It consists of a semi-circular piece of soft iron 9/32 in. by 31/31 in., with an inside diameter of 4 13/16 in. This is fixed to the projector barrel by two supports, so as to be concentric with the positive carbon. It is not fixed directly below the arc, as there it would soon be destroyed, but about 1¼ inch further along the length of the positive carbon. Even in this position it is frequently damaged by flames from the arc.

Observing for Searchlights.—As before stated, it is not practicable to observe and direct from the searchlight emplacement itself. Viewed from the projector house, the beam appears as a cylinder of white light ending abruptly in a blunt point, like a finger. It does not appear to be conical, and, curiously, a good beam has always the appearance of a slight belly in it. Objects caught by the beam near at hand shine up brightly like silver, but distant objects are not seen. Furthermore the glare tires the eyes, and unfits anyone there for observing objects out of the direct path of the beam. Viewed from a distance, however, the beam appears totally different. It is a common idea that the light is working well when the rays appear as dense white light. That, however, is simply a measure of atmospheric absorption, showing that there is a large quantity of haze or mist present. On a good clear night the beam is practically invisible, and its path is shown only by the objects it lights upon its sweeping round. On land the path is clearly marked as there is always some object for it to illuminate, but when it is sweeping a tract of still water it is often impossible to say whether the light is there or not. The beam is always brightest at the centre and fades off to a luminous haze at the outer edges. It is impossible to see a distant object through a beam, so that if two beams were out working parallel the observer could not see through the first beam the object on which the second might be focussed. Consequently, where there is more than one search-

light, the observer's station has to be located with considerable care.

Radius of Action of Searchlights.—Atmospheric absorption plays such a large part in the range of searchlights that it is most difficult to institute comparison. If two searchlights have to be compared they must both be tested at the same place, and time, as it would be practically impossible to reproduce exactly the same conditions with any certainty. Atmospheric absorption may amount in ordinary weather to anything from 4 per cent to 50 per cent and in the case of fogs to 100 per cent even. The larger the diameter of the searchlight as a rule the greater the range, but without knowing all such details as angle of beam, focus, diameter of source of light, intrinsic brilliancy of source, &c., it would be impossible to get even an idea of the proportion.

A German authority gives the following ranges for a 60-inch searchlight:—

Very clear atmosphere	10,000 yards or more.
Average atmosphere	6,000 to 8,000 yards.
Slight haze, or rain	3,000 to 4,000 yards.
Slight fog	1,000 to 2,000 yards.

but he does not give the actual illumination on the object.

Another authority gives for the same sized searchlight 32.25 lux or 3 candle feet at 2,000 metres or 2186 yards.

There is no doubt that in these latitudes we obtain much better results than in Europe, and the two following trials, made by myself with a 90 m.m. or 36-inch projector may be interesting:

1.—On an ordinary dark night I had the searchlight trained on a known rock, and from my position, 1,200 yards from the light, and practically the same distance further from the rock, I was able to take the range with the artillery range finder. The range was checked by the map and found to be very close it being 10,100 yards from my position and 9,000 yards approximately from the light.

2.—At the distance of 2 miles, 50 chains from the light, I was able to read pencil writing in my notebook.

It is on record that the lights at Fremantle have been seen out at sea at 120 miles from Fremantle, and a complaint was received from Pinjarra, that some signalling with lights was going on, and on investigation, this was also found to be due to the lights at Fremantle. In these cases the light must have been reflected from some low lying clouds.

I have no data as regards the beams from lighthouses, but some of these, specially when well elevated, have been sighted at immense distances.

Recent Improvements in Searchlights.—The improvements that have been effected have taken the form of decreasing the

size of the source of light, the crater of the positive carbon, and increasing its intrinsic brilliancy. Beck, in Germany, and Sperry, in the United States, have been greatly responsible for these advances. In the Sperry projector it is claimed that the c.p. of the arc, in spite of its smaller size, is increased from 50,000 to 90,000 candle-power. Also, owing to the smaller size of carbons employed, the area of the beam is reduced to one fourth, and the effective illumination increased six times. The Sperry lamp, of which a diagram is appended (Fig. 8), showing the carbon carriers, has the negative carbon at an inclination towards the positive. Carbons are impregnated with salts, the positive being 44 inches by $\frac{5}{8}$ inch, and the negative 7/16 inch. The current used is the same as for the $1\frac{1}{2}$ inch and 1 inch carbons, 150 ampères. In all lamps, however, that use such a high density of current and impregnated carbons, several special devices have to be employed. Owing to the great heat in the carbons and carriers, these have to be specially cooled. Some water-jacket the carriers, some pump air through the carriers and standards up round the carbons, and others inject nitrogen round the crater. The rapid rate at which the positive carbons burn require special feed arrangements. In the Sperry lamp this is done by a thermostat controlling the feed magnets in the base, the former being fixed on the barrel of projector so that as soon as the positive carbon is out of focus the light falls on to it, and actuates it. To keep the carbon crater in proper shape the positive carbon is slowly rotated all the time. Means have also to be provided for extracting the smoke and vapour caused by the combustion of the salts in the carbon. In most cases the use of nitrogen appears to increase the voltage required for the arc or between the carriers to 70 volts, and the cooling by air reduces it to 50 volts. The Sperry 36-inch 90 c.m. projector takes 75 volts at 150 ampères. An Italian projector is noted having in addition to the usual traversing and elevating motors, three others, one for rotating the carbons, one for injecting the air, and one for extracting the smoke.

It was stated that at the battle of Jutland the German searchlights were much superior to ours, and it was probably the Beck lamp that was used. It was also stated that after action had commenced some time the German firing became wild. It is quite possible that the sacrifice of simplicity had something to do with that as far as the searchlights went, for such a complicated piece of apparatus would fare badly on board ship in a naval action.

Small Projectors, Flood Lighting and Head Lights.—I have drawn attention to the improvement in kinema projection by the use of large glow lamps. In these small projectors the improvement has been twofold—in the lamps and in the choice

of the reflector. Lamps are now made focussing with the filament wound in a spiral, and much more compact, giving a much better light source. As regards reflectors, it has been pointed out by Lieut.-Commander Harrison that deep reflectors are more suitable for this work than the shallow reflectors usually employed for searchlights. Reflectors can be classed by the angle subtended by the source with the reflector, as follows:—Deep reflectors 270°, medium 180°, shallow 90°. The paraboloid used in the 90 c.m. diameter, 42 c.m. focus searchlight would be about 112°. Tests are given showing that with 100 c.p. lamps, and a 270° 8-inch diameter reflector a beam measured 140,000 c.p.

In a discussion on motor head lights at the American Illuminating Society it was stated that head lights in common use gave from 10,000 to 100,000 c.p. maximum in direction of beam. One concrete case was quoted of a test with a 12 volt lamp and 12 inch reflector enabling objects to be discerned at 700 yards in advance of the car.

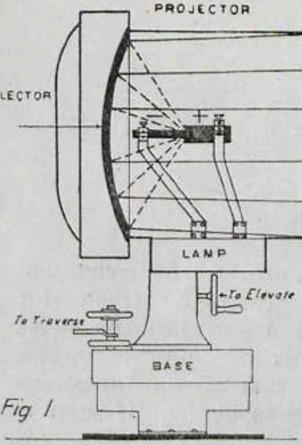
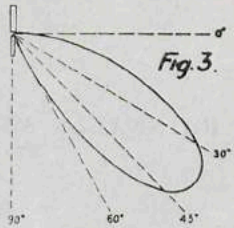
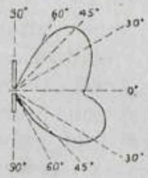


Fig. 1.



Curve of D.C. Arc.

Fig. 3.



Curve of A.C. Arc

Fig. 2

MANGIN REFLECTOR

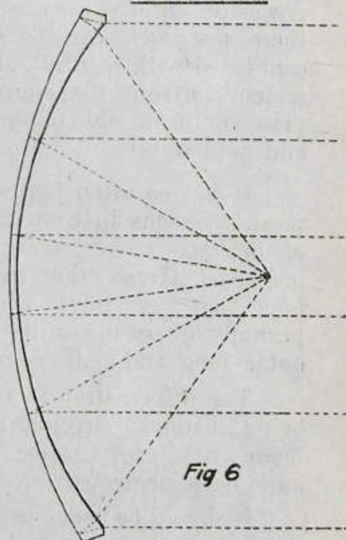
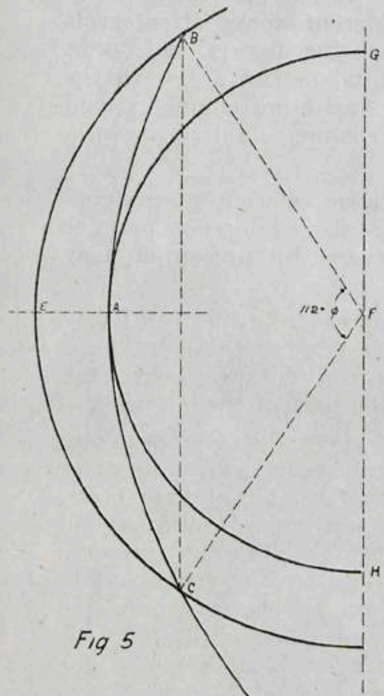
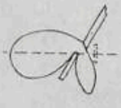


Fig 6





Inclined lamp

Fig. 4

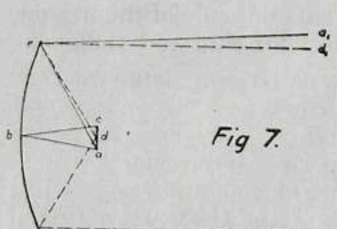


Fig 7.

Fig 5

BAC, parabolic curve, focus FA.

GAH, spherical curve, radius FA

BEC, spherical curve, cutting parabola at B and C

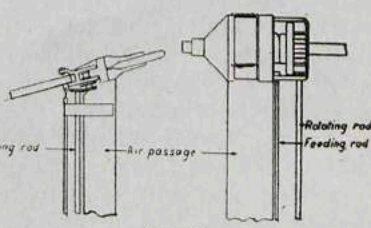


Fig 8

SPERRY SEARCHLIGHT

(August 13, 1919.)

RAINFALLS AND RUN-OFF FROM CATCHMENT AREAS.

By W. H. Shields.

Before any work for the conservation of water for irrigation, power or water supply, or the utilization of existing streams for these purposes, can be designed, there are certain problems connected with rainfall, absorption, percolation, and evaporation which confront the engineer, and somewhat similar questions arise in the design of drains and sewers to get rid of surplus and used water.

It has so often happened that the author has had to study these problems in connection with different works, at intervals of perhaps a few years, when convincing figures had to be produced afresh, that he thought of tabulating a few in the hope that they might aid the West Australian engineers, and perhaps others in similar climates, in coming to a decision without a long and tedious research.

The information in this paper is a compilation, no pretence being made to originality. In some cases reference may be made to where it came from; in others this precaution may have been neglected.

It should be borne in mind that data has to be very cautiously applied, each individual case needing careful consideration—and that no rule-of-thumb methods can do away with the necessity for skill and judgment on the part of the engineer.

In Australia data are few, with long distances between, and the engineer has to use his discretion as to how far they can be applied to the case he is considering; but that figures can be imported, interpolated with scanty local records, and applied with reasonable accuracy, is proved by the following. Figures arrived at in 1893, when preparing data for the water supply for the Yilgarn railway. There were no previous data for Western Australia, and very few records of rainfall along the railway route. The rain had been gauged at Northam for twelve years; Mooranoppin (66 miles East of Northam), five years; and Southern Cross (170 miles East of Northam) for four years. The Resident Engineer, Mr. Jas. Thompson (now Engineer-in-Chief for Western Australia) set the author to hunt up all available information concerning water supply, more especially in sub-tropical regions. From information culled from the "Proceedings" of the Institute of Civil Engineers, and else-

where, it was concluded that for the work in hand it would be well to assume that the annual evaporation would reach 7 ft., distributed somewhat as follows:—

January	16 per cent.	April..	6 per cent.
February	14 ,,	May	4 ,,
March	9 ,,	June..	3 ,,
July	3 per cent.	October	9 per cent.
August	3 ,,	November	12 ,,
September	6 ,,	December	15 ,,

Where no gauging had been done the following distribution of the rainfall was assumed for general purposes, for although the Northam end of the line is in the winter rainfall area, the Eastern end of the line is much more subject to summer showers, but is still principally a winter rain region:—

January	0 per cent.	July	27 per cent.
February	0 ,,	August	19 ,,
March	0 ,,	September	11 ,,
April	1 ,,	October	3 ,,
May	6 ,,	November	0 ,,
June	28 ,,	December	5 ,,

It was assumed, in the want of better knowledge, that the rainfall at Northam declined in a straight line curve to Mooranoppin, and thence again in a straight line curve to Southern Cross. Owing to the sudden and heavy downfalls of rain, up to three inches per hour and over, it was thought wise to allow for big bye-washes, varying from one foot for every four acres on small rock catchments, to one foot per sixty acres for larger mixed catchments. These figures are rather astounding when compared with the London drainage, but were deduced from returns from India, Persia, Egypt, Algiers, and Western America, and, having proved wonderfully correct, are interesting as tending to show how accurately data collected in one country can be applied to another if care is taken in the selection.

As the works proceeded, gauges were established at each reservoir, at first usually thirty to sixty miles apart, and later at intermediate dams. The rainfall is not always as uniform as the records tend to prove. On one occasion rain was registered at *all* the gauges on a regular falling grade, from 2½ inches at Northam to 1 inch at Kalgoorlie. On the evening of the next day, as the author drove into the Burracoppin catchment from the West, the dust was flying from the wheels of the buggy. When three or four hundred yards West of the dam, he inspected the walled drain along the rock, and found that it had not run, but on reaching the reservoir he found that it had gained 18 feet of water, which had come in by the Eastern drain, a little from the last hundred yards or so of the Western

drain, and yet the gauge on the bank gave a reading corresponding with its position on the grade from Northam.

Most authorities state that it is safe to take the mean of three dry years, that the average for the three driest years will not vary by more than one-sixth from the general mean, and that the driest known year will not be 30 per cent. less than the average for a period of many years—and, similarly, that the maximum will not be more than 50 per cent. above the mean.

It will be seen from Tables 1 and 2 hereunder that the minimum, while usually supposed to be at least 70 to 80 per cent. of the average in equable climates, may in a climate like that of Western Australia fall to 10 per cent. or even less of the average rainfall; while the maximum may soar to twice the average. Or, again, as much rain may fall in a single month, or even day, as would fall in the whole of another year.

All these falls are of importance, for when considering overflows, bye-washes and sewers, not only have the heaviest annual falls to be considered, but the maximum that may at any time fall in a short period; and it is, moreover, possible that such a fall may occur when the ground is saturated and the storage full. Again, when water has to be stored for town, railway, irrigation, or power supply, it is the minimum rainfall that has to be taken into account.

In the early railway water supplies for the Goldfields railway, it was considered that on account of the precarious nature of the rainfall for the district through which the railway passed, each reservoir should be of sufficient depth to hold two years' allowance for evaporation, consumption and absorption, should it receive no further increment after being filled. The Coolgardie water scheme was based on the storage being capable of yielding the maximum daily supply without being supplemented for three years.

It may be taken as axiomatic that the drier the climate the more erratic the rainfall and the smaller the catchment available the larger the storage required; whereas the wetter the climate, the more equable the rainfall, and the larger the catchment the smaller need the storage be.

Another factor that the engineer has to consider is what proportion of the annual rainfall will flow off and reach the dam site, and here no rule-of-thumb formula can be applied. It is a matter for the judgment of the engineer and is dependent on a number of factors, such as temperature, porosity, periods between and intensity of rainfalls. Reference to statistics published in the "Minutes of Proceedings" of the Inst. C. E., Vol. 81, pp. 250-251; Vol. 115, p. 49; Vol. 162, pp. 143 and 148; Vol. 164, p. 64, and Vol. 204, will show how extremely variable

are the stream discharges for corresponding total rainfalls under different conditions, even from the same catchment area. As a general rule, after a certain rainfall is reached for a given catchment, additional falls largely and sometimes almost entirely flow off. The water that will flow off certain soils and slopes, and the quantity that will flow for a given shower, is a matter requiring experience and sound judgment in the engineer in order to be able to calculate, and has to be considered for each individual case.

In the interior of Western Australia, both on the Railway and Goldfields water supplies, with which the author had to deal, no attempt was made to calculate what proportion of the annual rainfall would reach the reservoir; but each tank was taken separately and a tabulation made to show how much of each fall was likely to reach the dam, allowing that the falls were far enough apart for the pools to dry between times. This may sound like erring on the safe side, but the results proved the forecasts to be fairly good, *e.g.*, on the granitic bosses (30 to over 100 or more acres of nearly bare rock outcrops that had walled drains built around them) it was found that for falls of 10 points or under no water reached the tank, but that for over 10 points an ever increasing proportion of water was conserved, as the hollows and soiled areas filled up. On some of the more permeable catchments it was considered that no shower under 50 points caused any flow, but even then much depended on the nature of the rainfall, 20 points falling in two to five minutes, causing a far bigger flow than 60 points distributed over several hours. It must also be remembered that rain often falls on ground that is all fissured and almost too hot to touch, so that light rains falling gently disappear entirely, whereas a heavy downpour will run off almost anything.

For some of the phenomenal rainfalls given in Table 2 it can readily be imagined that the aqueducts (if the tank is elevated) and bye-washes need to be ample.

Town areas with paved streets and yards and much roofing are similar in nature to the rock catchments referred to above, while suburban areas with ribbon roads, gardens and lawns would not only yield much less, but it would take longer to reach the sewer.

The "Engineering Year Book" gives a formula whereby to calculate the run off, *viz.*:—

$$Q = Cr\left(\frac{i}{a}\right)^{\frac{1}{4}}$$

where Q = the number of cubic feet per second per acre reaching the sewer; C = a constant varying from 0.75 for populous towns to 0.30 for suburbs; r = the rainfall in cubic feet per

acre; I = the average fall per 1,000 ft. towards the sewer; a = the number of acres drained.

In sewer design it is necessary to remember that long sewers have considerable storage and that the water takes some considerable time to collect; also that a certain amount of temporary flooding is perhaps permissable in exceptionally heavy rain.

On the inland portion of Western Australia the method of determining the quantity of water to flow off a catchment is rather different from what it is in most places. The streams seldom run and there is usually no one near to gauge them when they do run. Observations have shown that when 0.10 inch of rain had fallen on a bald rock water began to flow, and as the rain increased more and more of the rock shed the water falling on it, as the natural holes and crevices filled up. A table was accordingly made showing how much of each class of catchment area was estimated to give an off-flow when the rain reached a certain amount. These were added together and plotted, and the same repeated for other rainfalls, and a curve run through to even up the figures (see Diagram 1). *E.g.*, suppose the catchment area is 1,200 acres, whereof about 40 acres of bare rock lie close to the tank; assume that at 0.10 inch of rainfall water begins to run down the channel from the rock—0.10 inch, therefore, corresponds with 0 per cent. of catchment shedding. Again, suppose that 0.50 inch of rain has fallen in a smart shower:—We may assume that the 40 acres of rock is now shedding about 90 per cent. of the water falling on it, and about 80 acres of clay country is sending in its quota of, say, 5 per cent. There will now be running off about 34 per cent. of the water falling on the 120 acres, or, say, 3 per cent. of the water falling on the whole catchment. As another example, suppose 1 inch of rain to have already fallen steadily, and that it is still raining: it is safe to assume that the 40 acres of rock is now sending in about 100 per cent. of the water falling on it. The 80 acres of clay may be sending in 60 per cent., and an additional 300 acres has come in, and is at the moment yielding 26 to 27 per cent.

Thus by the careful study of the catchment area the curves c and w are plotted, as in the imaginary case on Diagram 1, and from w a third curve is plotted showing the yield in gallons of varying showers or rainfall.

At Southern Cross a neatly concreted little reservoir in New Zealand Gully had never been known to catch any water. The author was sent up to report, and recommended the pulverising of the surface of the friable red soil, composing a large portion of the catchment, by dragging a loaded sledge over it and inducing rapid drainage by steeply falling gathering drains.

Since this was done the reservoir has never lacked water. This subsequently became a recognised system, and was put into use in a great many places.

From Mr. Ernest Lloyd Davis (Min. Proc. I.C.E., Vol. 164) have been culled two diagrams, Nos. 2 and 3, the former giving the percentage of a town area that may be assumed as impervious in terms of the population, and the latter giving the average intensity of the various showers falling at Birmingham during four years, in terms of their duration.

Tables 1, 2 and 4 give some data of rainfall, with numerous interesting figures. Those for Australia, Mr. Curlewis, of the weather bureau, was kind enough to let me glean from the official records.

It is to be noted that very heavy falls take place in short periods, often tailing out to a comparatively light rain for some hours—*e.g.*, in a 3½-inch rain the 3 inches may fall in 20 minutes, the other ½ inch taking from half an hour to several hours to fall, and sometimes over an inch falls in five minutes. A diagram such as No. 2 could be compiled for Australia, but showing much heavier falls in the vertical column. In the same locality, height and forests have a great effect on rainfall, *e.g.*, at 500 ft., 46.6 ins.; at 800 ft., 50.5 ins.; at 1,700 ft., 52.1 ins.; at 1,750 ft., 56.5 ins.; at 1,800 ft., 62.1 ins. The rainfall gauged in a Gippsland forest is even more startling compared with gaugings taken all round. (See Victorian Royal Commission on Timber.)

Another question that has to be considered is what quantity of water will be required for any given purpose. One purpose for which it is easy to give figures is town water supply, and these will be found to vary very considerably according to locality and the habits of the inhabitants, from 10 gallons per head to 150 gallons per head per day.

It is evident that the habits of the natives and the manner in which the water is distributed will influence the consumption. For instance, take a native town in India, where it has been the practice to draw from wells: water is brought into the town, and standpipes are fixed at the intersections of the streets, but it is not reticulated in the ordinary sense of the word. Then ten gallons per head will probably meet all demands. Take, on the other hand, an English town, with water laid on to the kitchens, baths and water-closets, then 25 gallons may meet all requirements. But where water is used for manufacturing and other purposes it may run into much larger figures. For instance, at Burton-on-Trent, the brewing town uses 130 gallons per head, whereas the residential town East of the river only uses 25 gallons per head, but the local government insist on the sewage being diluted with five times this amount. Sixty gallons

per head is considered ample for ordinary Australian towns, yet in some American cities it runs up to nearly 200.

Among the losses, absorption and percolation are so closely connected with each individual case that no rule can be given, cases occur such as that at Boorabbin, where what appeared to be clay, acted like a sieve and on examination, after the escape of the water, was found to be honeycombed by termites or other borers, the workings being hidden by the debris they contained. This led to the puddle having to be carried down over 50 feet to the rock, when the tank became water-tight. In small conservations, it is usual to make the tank pretty water-tight and in large ones to do so as far as conveniently possible. For where a certain amount of percolation can be tolerated at first, silt carried by the inflowing water will in time, fill all pores and provide a water-proof film over the bottom. The absorption also becomes as a rule small after a time and may be added to the evaporation.

A factor that cannot be neglected in water conservation is evaporation. Evaporation varies with the climate, but is always to be relied upon. It probably reaches its maximum in the subtropics inland, where the atmosphere is less moist than in the tropics, the actual temperature being also probably greater. Heat and wind affect it but the hottest days do not show the highest evaporation. It is greater from shallow than from deep water and more in summer than winter. It is enormously reduced, if not eliminated, by roofing the tank, thus shutting off the direct action of the wind and maintaining a moisture laden atmosphere. Roofing is only possible for small reservoirs. Up to the present, at all events, it has been considered too costly for large ones. It is, of course, a matter of finance, whether it is cheaper to provide a roof or to store more water. Different authorities give the average evaporation from reservoirs in temperate climates as from 1/6 in. to 1/16 in. per day. In most tropics, it is put down as $\frac{1}{8}$ in. to $\frac{1}{4}$ in. per day. In England and Scotland, evaporation is stated to be from 22 ins. to 38 ins. per annum and in Paris 34 ins.

The evaporation from the water surface of the reservoirs at Tanza, and Baroda (Min. of Proc. I. C. E., Vol. 115) was 6 feet for 9 dry months, of which 2.94 feet and 2.96 feet respectively, were for 151 days, January to May inclusive. At Nagpur from 10th October, 1872, to 9th June, 1873, 242 days, covering the winter months, the evaporation was 4 feet and in the dry season, 1872-73, the evaporation exceeded 50 per cent of the storage. In the Tanza case, 6 feet of evaporation would represent one-third of the total quantity collected.

Diagram No. 4, shows graphically, the distribution through-

out the year of the mean evaporation at some Australian towns and diagram No. 5, is a map given by the meteorological department to show the evaporation in various parts of the Commonwealth.

Table No. 3, gives some evaporation records for Western Australia.

The paper is accompanied by a number of tables, the more important of which may be found from the references given below :—

1. Comparison of Rainfall and Storm-water Discharge (Min. of Proc. of Inst. C.E., Vol. 164, p. 64).
2. Allowances for Storm-water Discharge in London (compiled from Min. of Proc. of Inst. C.E., Vols. 24 and 204, principally).
3. Discharge and Rainfall, Surya River, 1885-1889 (Min. Proc. Inst. C.E., Vol. 115, p. 49).
4. Typical Mean Annual Values of Run-off (General Electric Co.'s Technical Letters, No. 316).
5. Typical Variations in Stream Flows (Report of U.S. Geological Survey on Stream Measurements in 1904).
6. Buffalo River, South Africa: Rainfall and Discharge (Min. Proc. Inst. C.E., Vol. 81, pp. 250, 251).
7. Rainfall and Yield of Sweetwater River (Min. Proc. Inst. C.E., Vol. 162, p. 143).
8. Exceptionally Small Annual Stream Flows (Min. Proc. Inst. C.E., Vol. 162, p. 148).
9. Rainfall, Temperature, Evaporation: Italy, Algiers, Spain, Madras (Min. Proc. Inst. C.E., Vol. 27).

Diagrams 6 to 8 give the annual rainfalls at various places in Western Australia where records have been taken for many years.

Diagram No. 9 gives the mean monthly rainfalls of the principal cities in Australia.

The author would have liked to determine, if the records showed that a law could be picked out governing the recurrence of good or bad years, but the data available appear insufficient and further research in this direction is suggested.

TABLE No. 1.—**Rainfalls in Western Australia to 1917.**

100 Points to 1 Inch of Rain.

Locality.	Average.		Maximum.			Minimum.			Maximum Month.		Longest Period with no rainfall.	
	Period in Years.	Per Year.	Year.	Points.	Ratio to Mean.	Year.	Points.	Ratio to Mean.	Month.	Points.	No. of Months.	Year.
From North to South –												
Wyndham	30	2,697	1903	5,325	1·98	1905	1,440	0·53	Jan., 1903	2,824	6	1911, 1912, 1913
Turkey Creek ...	20	3,108	1903	5,041	1·62	1900	1,449	0·47	Jan., 1914	1,967	5	
Hall's Creek	27	2,101	1903	4,202	2·00	1905	854	0·41	Jan., 1903	1,697	6	1902
Fitzroy	24	2,258	1916	3,195	1·42	1909	1,095	0·49	Feb., 1895	1,671	7	1912
Derby	32	2,707	1917	4,985	1·85	1911	1,343	0·5	Feb., 1917	3,165	7	
Broome	28	2,364	1896	4,307	1·82	1891	641	0·27	Feb., 1896	2,358	8	1896
La Grange Bay ...	27	1,921	1898	3,818	1·99	1891	262	0·24	Feb., 1902	1,404	9	1896
Wallal	21	1,333	1907	2,203	1·65	1911	580	0·44	Jan., 1907	1,364	8	
Condon	28	1,307	1901	2,405	1·84	1891	585	0·45	Mar., 1899	1,360	9	1894
Bamboo Creek ...	20	1,599	1899	3,492	2·2	1903	569	0·35	Mar., 1899	2,033	7	1912
Marble Bar	23	1,408	1899	2,920	2·08	1913	743	0·53	Jan. 1917	1,219	8	1912
Nullagine	20	1,321	1899	2,337	1·77	1913	607	0·46	Jan. 1899	1,175	5	
Port Hedland ...	20	1,301	1899	2,680	2·06	1914	611	0·47	Jan. 1901	1,432	9	1912
Whim Creek	20	1,822	1898	4,784	2·63	1905	803	0·44	Mar. 1899	2,802	9	1912
Roebourne	31	1,235	1899	4,173	3·38	1891	13	0·01	Mar., 1898	1,464	16	1891
Cossack	36	1,218	1900	4,003	3·3	1891	34	0·03	April, 1900	2,056	19	1890–1892
Fortescue	30	1,048	1890	3,566	3·4	1891	42	0·04	May, 1890	2,650	20	1890–1892
Onslow	32	851	1900	2,696	3·18	1912	57	0·07	April, 1900	1,100	19	1911–1913
Winning Pool ...	20	1,078	1909	2,272	2·25	1912	471	0·44	Feb., 1918	1,186	5	
Carnarvon	35	928	1893	1,652	1·78	1891	266	0·28	June, 1895	865	9	

Rainfalls in Western Australia to 1917 (*Continued*).

Locality.	Average.		Maximum.			Minimum.			Maximum Month.		Longest Period with no rainfall.	
	Period in Years.	Per Year.	Year.	Points.	Ratio to Mean.	Year.	Points.	Ratio to Mean.	Month.	Points.	No. of Months.	Year.
Junction Police Station	10	854	1918	1,375	1·6	1911	254	0·30	June, 1908	383	5	
Sharks Bay	24	908	1908	1,873	2·06	1894	343	0·38	June, 1917	520	6	
Wooramel	19	890	1908	1,521	1·71	1911	288	0·32	July, 1904	638	7	
Hamelin Pool ...	32	784	1889	1,457	1·86	1911	240	0·31	July, 1905	511	8	
Peak Hill	20	1,044	1900	2,499	2·38	1898	175	0·17	April, 1901	988	4	
Meekatharra	9	1,153	1915	2,031	1·76	1911	487	0·42	Mar., 1917	608	5	
Gabanintha	18	984	1915	1,912	1·94	1911	535	0·55	April, 1900	837	5	
Nannine	23	861	1915	1,753	2·04	1898	210	0·24	Jan., 1902	838	6	
Cue	23	872	1900	1,975	2·26	1911	309	0·35	April, 1900	832	5	
Day Dawn	23	843	1900	1,640	1·94	1899	355	0·42	April, 1900	695	5	
Lake Austin	20	957	1915	2,122	2·22	1899	303	0·32	Aug., 1906	545	5	
Lennonville	17	988	1915	1,800	1·82	1911	275	0·28	Jan., 1909	615	3	
Mt. Magnet	23	905	1915	2,527	2·8	1911	289	0·32	Jan., 1909	440	4	
Yalgoo	21	954	1917	1,784	1·87	1911	369	0·38	Feb., 1918	700	4	
Murgoo	29	833	1915	1,842	2·32	1900	313	0·37	June, 1897	486	7	
Northampton ...	36	2,038	1917	3,085	1·52	1891	1,120	0·55	June, 1883	1,064	5	
Mullewa	22	1,291	1915	2,364	1·83	1911	685	0·53	Aug., 1909	936	5	
Geraldton	40	1,865	1917	3,365	1·80	1891	345	0·18	June, 1890	1,292	6	
Greenough	35	1,918	1890	3,697	1·93	1914	997	0·5	May, 1889	1,031	5	
Dongarra	35	1,836	1889	2,876	1·57	1914	1,001	0·54	June, 1890	1,402	3	
Mingenew	22	1,636	1917	2,912	1·78	1914	700	0·43	Aug., 1909	763	4	
Carnamah	30	1,573	1917	3,078	1·95	1914	835	0·53	July 1917	643	5	
Dandaragan	20	2,561	1917	5,238	2·04	1914	1,031	0·40	June, 1918	1,064	4	
Moora	20	1,853	1917	3,105	1·68	1914	796	0·43	July, 1917	772	3	
Walebing	34	1,949	1917	3,471	1·78	1914	1,210	0·62	July, 1910	686	3	
New Norcia	35	2,119	1917	3,730	1·77	1911	1,246	0·62	July, 1917	915	7	
Gingin	29	3,050	1917	4,332	1·42	1914	1,266	0·41	June, 1900	1,242	3	

Rainfalls in Western Australia to 1917 *(Continued)*

Locality.	Average.		Maximum.			Minimum.			Maximum Month.		Longest Period with no rainfall.	
	Period in Years.	Per Year.	Year.	Points.	Ratio to Mean.	Year.	Points.	Ratio to Mean.	Month.	Points.	No. of Months.	Year.
Metropolitan—												
Chidlow's Well ...	10	3,853	1917	5,511	1·43	1914	1,847	0·48	June, 1910	1,427	4	
Mundaring	8	4,306	1917	5,879	1·37	1914	2,571	0·6	July, 1917	1,389	3	
Armadale	17	3,482	1917	5,390	1·55	1914	1,965	0·56	June, 1917	1,296	4	
Guildford	38	3,338	1917	4,641	1·39	1914	1,951	0·58	July, 1917	1,183	5	
Perth	42	3,353	1890	4,673	1·39	1917	2,021	0·6	May, 1879	1,213	3	
Fremantle	40	2,922	1890	4,638	1·58	1877	1,630	0·56	June, 1890	1,358	3	
Rottnest	36	2,757	1887	4,392	1·59	1914	1,609	0·58	July, 1887	1,359	4	
Jarrahdale	35	4,569	1917	8,540	1·87	1894	2,390	0·52	July, 1917	2,011	4	
South-West -												
Mandurah	28	3,553	1890	4,866	1·37	1914	2,185	0·61	June, 1906	1,246	4	
Pinjarra	39	3,794	1917	5,331	1·41	1877	2,230	0·58	Aug., 1895	1,307	3	
Brunswick	9	4,052	1917	5,679	1·4	1914	2,863	0·7	June, 1917	1,448	3	
Collie	18	3,785	1917	5,769	1·51	1914	2,637	0·7	Aug., 1913	1,136	3	
Bunbury	41	3,608	1890	5,374	1·49	1914	2,502	0·69	June, 1895	1,479	4	
Donnybrook	17	3,840	1917	5,944	1·55	1911	2,670	0·69	July, 1907	1,029	4	
Greenbushes	25	3,830	1917	6,620	1·72	1894	2,853	0·74	June, 1917	1,574	3	
Bridgetown	30	3,352	1917	5,680	1·9	1911	2,335	0·7	June, 1895	1,223	4	
Busselton	37	3,122	1917	4,764	1·53	1891	2,102	0·07	June 1917	1,463	4	
Karridale	24	4,671	1917	7,952	1·71	1911	3,469	0·74	May, 1917	1,592	1	
Cranbrook	25	1,953	1917	2,915	1·49	1891	1,293	0·64	June, 1910	575	4	
Denmark	16	4,809	1917	6,724	1·4	1911	3,416	0·71	July, 1910	1,324	1	
Great Southern—												
Beverley	17	1,666	1909	2,429	1·46	1914	851	0·51	June, 1900	548	5	
Pingelly	27	1,681	1917	2,424	1·44	1914	852	0·51	June, 1900	526	6	
Narrogin	26	1,940	1917	2,901	1·58	1901	1,340	0·73	July, 1907	630	5	
Wandering	29	2,385	1905	3,849	1·61	1914	1,392	0·58	June, 1900	1,098	6	
Marradong	20	1,825	1917	3,940	2·16	1914	1,585	0·87	May, 1905	971	4	
Williams	33	2,123	1917	2,842	1·33	1911	1,251	0·59	June, 1900	769	5	
Wagin	27	1,728	1917	2,373	1·37	1911	1,185	0·68	July 1907	501	5	

Rainfalls in Western Australia to 1917 *(Continued)*.

Locality.	Average.		Maximum.			Minimum.			Maximum Month.		Longest Period with no rainfall.	
	Period in Years.	Per Year.	Year.	Points.	Ratio to Mean.	Year.	Points.	Ratio to Mean.	Month.	Points.	No. of Months.	Year.
Katanning	26 to 1918	1,812	1917	2,566	1·42	1891	1,236	0·68	July, 1898	534	5	
Kojonup	34	2,216	1903	3,547	1·6	1911	1,498	0·68	June, 1917	769	2	
Broomehill	28	1,848	1903	3,518	1·9	1891	1,227	0·66	April, 1913	643	4	
Mt. Barker	30	2,873	1917	4,326	1·5	1891	1,827	0·63	July, 1912	1,027	1	
Albany	41	3,627	1917	5,374	1·48	1881	2,507	0·69	Aug., 1886	1,124	2	
Eastern Railway—												
Dowerin	13	1,510	1917	2,599	1·72	1914	570	0·38	July, 1917	559	5	
Goomalling	17	1,397	1917	2,250	1·61	1914	589	0·42	July, 1915	514	6	
Toodyay	38	2,105	1917	3,610	1·72	1914	998	0·47	July, 1917	1,012	6	
Northam	37	1,670	1917	2,776	1·66	1914	764	0·45	...	...	4	
York	41	1,756	1917	2,656	1·51	1914	709	0·4	Aug., 1882	665	4	
Meckering	20	1,565	1915	2,260	1·45	1914	784	0·5	May, 1908	623	6	
Cunderdin	12	1,477	1915	2,339	1·58	1914	571	0·39	July, 1912	477	3	
Kellerberrin	25	1,281	1917	2,377	1·85	1914	678	0·53	April, 1909	396	6	
Tammin	6	1,371	1917	2,260	1·65	1911	474	0·34	July, 1917	465	5	
Doodlakine	6	1,256	1917	2,194	1·75	1914	568	0·45	June, 1917	312	3	
Merredin	14	1,218	1917	2,166	1·78	1914	512	0·42	July, 1917	460	4	
Burracoppin	17	1,165	1917	2,434	1·2	1911	495	0·42	Aug., 1910	486	6	
Boorabbin	22	1,074	1909	1,423	1·32	1895	534	0·5	Mar., 1917	410	3	
Southern Cross ...	29	1,039	1917	1,714	1·66	1894	512	0·49	Feb., 1918	484	5	
South-East Coastal —												
Bremer Bay	34	2,424	1917	3,570	1·51	1896	1,738	0·72	May, 1918	703	2	
Hopetown	17	2,055	1917	2,704	1·32	1912	1,231	0·6	Feb., 1915	494	2	
Ravensthorpe ...	17	1,676	1917	2,314	1·31	1907	1,184	0·67	Dec., 1913	551	2	
Esperance	35	2,532	1917	3,114	1·23	1896	1,744	0·69	Aug., 1915	710	2	
Israelite Bay ...	34	1,502	1917	2,836	1·89	1897	868	0·58	Mar., 1917	537	2	
Balladonia	28	975	1917	1,758	1·8	1891	385	0·39	June, 1898	490	5	
Eyre	34	1,134	1917	1,984	1·75	1894	613	0·54	June, 1899	480	2	

Rainfalls in Western Australia to 1917 (*Continued*).

Locality.	Average.		Maximum.			Minimum.			Maximum Month.		Longest Period in which no rainfall.	
	Period in Years.	Per Year.	Year.	Points.	Ratio to Mean.	Year.	Points.	Ratio to Mean.	Month.	Points.	No. of Months.	Year.
Eucla	43	1,004	1896	1,485	1·48	1897	537	0·53	Feb., 1896	680	3	
Goldfields—												
Mt. Sir Samuel ...	18	853	1917	1,514	1·70	1910	448	0·62	Mar., 1917	840	4	
Lawlers	22	819	1917	1,452	1·78	1910	334	0·41	Mar., 1917	932	9	
Mt. Leonora	21	864	1915	1,415	1·64	1910	464	0·54	Mar., 1917	557	6	
Mt. Malcolm	21	828	1918	1,653	2·0	1898	424	0·51	April, 1918	575	5	
Mt. Morgans	19	874	1915	1,476	1·69	1910	390	0·45	April, 1918	512	6	
Laverton	19	964	1900	1,550	1·61	1911	529	0·55	Nov., 1914	598	6	
Murrin Murrin ...	20	874	1915	1,385	1·59	1910	423	0·48	Mar., 1907	661	6	
Kookynie	15	940	1915	1,561	1·66	1911	681	0·72	Feb., 1915	564	5	
Menzies	22	944	1915	1,884	2·0	1898	445	0·47	Feb., 1901	378	5	
Mulline	17	1,141	1915	1,737	1·52	1905	630	0·55	Oct., 1909	482	5	
Davyhurst	17	1,151	1915	1,670	1·45	1911	486	0·42	April, 1908	592	4	
Goongarrie	23	934	1906	1,289	1·38	1899	413	0·44	Feb., 1906	520	5	
Broad Arrow ...	20	1,001	1915	1,607	1·60	1911	468	0·46	Mar., 1912	400	3	
Kanowna	23	963	1915	1,911	1·98	1911	546	0·47	Mar., 1896	746	3	
Bulong	22	958	1915	1,799	1·88	1897	524	0·55	Feb., 1915	739	5	
Kalgoorlie	23	976	1915	1,643	1·68	1897	475	0·48	Mar., 1917	502	4	
Coolgardie	26	990	1915	1,761	1·78	1893	354	0·36	Aug., 1906	327	5	
Burbanks	20	1,001	1917	1,232	1·23	1911	500	0·5	Mar., 1917	370	3	
Norseman	22	1,106	1915	1,813	1·64	1911	543	0·49	Feb., 1915	512	2	
Sandstone	14	914	1915	1,790	1·96	1911	372	0·40	Mar., 1917	668	4	
Wiluna	20	1,031	1900	2,803	2·7	1910	192	0·19	April, 1900	2,075	5	

Under the heading "Longest period in which no rainfall" are included, in some cases, falls where up to 10 points of rain were registered on one or more occasions.

TABLE 2.—Heavy Rainfalls recorded in Western Australia.

Locality.	Fall. Points.	Period. Hours.	Date.
Albany	240	24	28–7–98
Ajana	263	24	15–1–98
Arrino	395	24	21–1–16
Breaksea	240	...	28–1–98
Bamboo Creek	1,010	...	22–3–99
Broomehill	205	11 p.m. to 3 a.m.	11, 12–2–99
Balla Balla	1,440	...	21–3–99
Balbarrup...	129	Half-hour	25–4–01
Boodarie	1,453	...	21–3–99
Bremer Bay	435	24	3–4–08
Beverley	160	25 minutes	10–4–08
Bruce Rock	118	15 minutes	26–1–15
Bridgetown	234	24	16–1–15
Boyanup	284	24	26–2–15
Bedfordale	284	24	26–2–15
Bunbury	338	24	26–2–15
Bannister	264	24	26–2–15
Beverley	308	24	28–1–16
Baandee	223	24	21–1–16
Bruce Rock	217	24	21–1–16
Berkshire Valley	208	24	19–3–17
Burbanks	350	24	19–3–17
Bruce Rock	368	24	19–3–17
Boojerakine	241	24	19–3–17
Byanda	438	24	19–3–17
Baandee, N.	445	24	19–3–17
Bruce Rock, S.	373	24	19–3–17
Belka	468	24	19–3–17
Bungulla, N.	347	24	19–3–17
Chinginarra	305	80 minutes	24–2–99
Coolgardie	308	3 a.m. to 8 a.m.	...
Do.	150	1 hr. 10 min.	10–3–07
Corrigin	350	24	29–11–13
Do.	365	24	20–12–13
Cossack	1,323	...	16–4–00
Chillingup	325	24	11–4–13
Do.	401	24	12–4–13
Do.	220	24	10–7–12
Do.	217	24	9–10–11
Carnarvon	260	9·30 to 11 p.m. (1½ hours)	9–2–14
Corrigin	140	40 minutes	24–8–15
Cardonia	404	24	19–3–17
Currow	278	24	19–3–17
Cowcowing Centre	381	24	19–3–17
Cowcowing	316	24	19–3–17
Totagin	470	24	19–3–17
Cuttening	271	24	19–3–17
Codg Codgin	359	24	19–3–17
Chapman, East	296	24	19–3–17

Heavy Rainfalls recorded in Western Australia (*Contd*).

Locality.	Fall. Points.	Period. Hours.	Date.
Cottesloe Beach	141	55 minutes	30–6–17
Cue	130	30 minutes	1–1–18
Derby	1 309	...	29–12–98
Dongarra	326	24	26–2–15
Donnybrook	292	24	26–2–15
Doodarding Well	402	24	19–3–17
Doodlakine	466	24	19–3–17
Dowering	237	24	19–3–17
Esperance	232	20	11–8–97
Eyer	54	10 minutes	22–11–10
Ejandine	300	2	25–2–15
Enegee	247	24	26–2–15
Forest Hill	315	15	8, 9–10–05
Fortescue	2,336	...	3–5–00
Fremantle	340	24	26–2–15
Globe Hill	600	24	26–2–99
Grassmere	80	7 minutes	11–3–04
Greenbushes	60	20 minutes	7–2–07
Guildford	120	40 minutes	3–8–09
Geraldton	330	50 minutes	1–8–09
Do.	324	24	26–2–15
Greenough	310	24	26–2–15
Giggerwillie	398	24	19–3–17
Glen Erin	419	24	19–3–17
Gunwarrie	200	15 minutes	31–3–18
Do.	278	24	31–3–18
Harvey	199	24	21–5–14
Hopetoun	334	24	21–12–13
Henley Park	118	35 minutes	30–12–14
Hamelin Pool	272	24	26–2–15
Hill River	205	24	26–2–15
Hines Hill	282	24	19–3–17
Hill River	230	24	...
Harrismith	400	24	26–1–18
Kalgan River	209	24	26–1–18
Kojonup	254	24	26–1–18
Jarrahdale	311	2½	24–5–98
Do.	211	2	2–8–98
Jarrahdale Mill	220	24	26–2–15
Karridale	350	8 a.m. to noon	2–8–98
Do.	68	Noon to 6 p.m.	2–8–98
Do.	300	10·30 to noon	2–8–98
Kellerberrin	150	20 minutes	28–6–12
Kirupp	346	24	26–2–15
Karridale	318	24	26–2–15
Karinia	522	24	19–3–17
Killarney	246	24	19–3–17
Cape Leeuwin	145	4	2–8–98
Londonderry	70	15 minutes	23–2–99
La Grange Bay	185	35 minutes	20–3–00
Lake Austin	130	20 minutes	10–5–03
Laverton	104	1	19–1–06

Heavy Rainfalls recorded in Western Australia *(Contd.)*

Locality.	Fall. Points.	Period. Hours.	Date.
Lawlers	107	7 minutes	17–7–07
Mandalup	50	10 minutes	26–3–01
Mt. Jackson	84	20 minutes	26–2–03
Menzies	61	14 minutes	2–3–03
Do.	145	35 minutes	22–2–03
Mandurah	380	24	11, 12–7–07
Do.	105	30 minutes	10–8–11
Morowa	220	1	4–12–14
Mayfield	354	2½	15–1–15
Mundaring	360	24	26–2–15
Marradong	318	24	26–2–15
Mt. Magnet	225	20 minutes	28–1–16
Millstream	1,000	...	5–3–00
Minnivale	367	24	19–3–17
Melrose	325	24	19–3–17
Moora	275	24	19–3–17
Merredin	325	24	19–3–17
New Norcia	140	20 minutes	6–3–94
Nantara	96	12 minutes	20–2–99
Perth Observatory	103	25 minutes	27–5–98
Do.	130	4	19–8–98
Peak Hill	675	3	14–3–00
Perth Observatory	66	15 minutes	10–7–01
Plympton	599	4	0–2–03
Perth Observatory	262	10	29, 30–4–04
Do.	49	15 minutes	29–9–06
Peak Hill	179	1	6–3–07
Port Hedland	585	4½	20–8–19
Pingelly	100	10 minutes	26–11–10
Point Cloates	1,087	...	20–1–09
Quindalup	300	2	23–5–98
Ruby Plains	345	45 minutes	23–3–04
Roebourne	1,144	...	3–4–98
Rottnest	316	24	26–2–15
Sorrento	312	1	4–12–14
Thango	2,418	...	17 to 19–2–96
Turkey Creek	140	1	24–2–99
Do.	110	10 minutes	9–4–03
Do.	259	...	19 to 24–12–13
Do.	162	...	19 to 24–12–13
Do.	282	...	19 to 24–12–13
Do.	153	...	19 to 24–12–13
Do.	130	...	19 to 24–12–13
Do.	97	...	19 to 24–12–13
Tambrey	170	30 minutes	14–2–00
Tammin	120	12 mnutes	29–12–12
Tammin	215	...	19–3–17
Tantegin	429	...	19–3–17

Heavy Rainfalls recorded in Western Australia *(Cont*

Locality.	Fall. Points.	Pexiod. Hours.	Date,
Wyndham	350	30 minutes	12-1-99
Whim Creek	300	25 minutes	5-3-00
Do.	211	40 minutes	27-3-00
Wickepin	118	2½	24-4-00
Wandering	131	30 minutes	7-3-06
Whim Creek	2,941	...	3-4-98
Williambury	255	2	27-4-93
Wagin	315	6	7-4-08
Wilson's Inlet	595	24	10-3-17
Wad'ering Park...	551	...	19-3- 7
Wyndham	1,250	...	4-3-18
Yarraloola	330	50 minutes	26-2-99
Yoting	195	24	20-12-13
Yerilla	191	45 minutes	30-12-14
Williams Bay	304	4	12-4-13
Do.	944	24	10-3-17
Do.	800	12	...

South Australia.

Borroloola	1,440	...	14-3-99
Lake Nash	1,025	...	21-3-01
Pine Creek	1,035	...	8-1-97
Port Darwin	1,167	...	7-1-97
Powell's Creek	819	...	27-2-10
Tennant's Creek	922	...	28-2-10

Queensland.

Anglesey	1,820	...	26-12-09
Ayr	1,458	...	20-9-90
Bloomsbury	1,740	...	14-2-93
Bowen	1,465	...	13-2-93
Brisbane	1,831	...	31-1-87
Do.	1,118	...	14-3-08

Heavy Rainfalls.

Locality.	Fall. Points.	Period. Hours.	Date.
Queensland—			
Buderim, Mt.	2,620	...	11–1–98
Burketown	1,452	...	12–3–03
Cairns	2,016	...	2–4–11
Cardwell	1,824	...	18–3–04
Crohamhurst (Blackall Range) ...	3,571	...	2–2–93
Dungeness	2,217	...	16–3–93
Geraldton	2,122	...	29–12–03
Do.	2,050	...	7–4–12
Harvey Creek	2,775	...	3–1–12
Innisfail	2,050	...	7–4–11
Kuranda	2,880	...	2–4–11
Macnade Mill (Townsville) ...	2,333	...	6–1–01
Mambour	2,100	...	9–1–98
Woodlands (Yeppoon)	2,307	...	31–1–93
Yandina	2,008	...	1–2–93
Yarrabah	3,065	...	2–4–11
Yeppoon	2,005	...	31–1–93
New South Wales—			
Albury	1,070	...	14–2–98
Anthony	1,714	...	28–3–87
Billambill	1,294	...	14–3–94
Broger's Creek	2,005	...	14–2–98
Broger's Creek, Upper	2,083	...	13–1–11
Bulli Mountain	1,714	...	13–2–98
Condong	1,866	...	27–3–87
Cordeau River	2,258	...	14–2–98
Kembla Heights	1,746	...	13–1–11
Liverpool	1,039	...	23–2–74
Macksville	1,000*	...	23–2–08
Madden's Creek	1,868	...	13–1–11
Morpeth	2,152	...	9–3–93
Nepean Tunnel	1,230	...	14–2–98
Newcastle	1,117	...	19–3–71
Parramatta	1,194	...	28–5–89
Southhead (near Sydney) ...	2,012	...	29–4–41
Toowomba	2,000	...	5–3–93

* 6·50 inches in two hours.

Not in Australia.

Philadelphia—Heaviest in one day, in August, 1873—7·3 inches; also in July, 1842—6 inches in two hours.
Morristown (Pennsylvania)—In 1865—9 inches in five hours.
Genoa—On one occasion—32 inches in 24 hours.
Geneva—6 inches in three hours.
Marseilles—13 inches in 14 hours.
Chicago—0·97 inches in seven minutes.

TABLE 3.—**EVAPORATION.**

Average Monthly in inches.

—	Cue.	Wiluna.	Laverton.	Cool-gardie.	Car-narvon.	Marble Bar, 1916.	Narrogin State Farm, 1917.	Chapman State Farm, 1918.	Merredin, 1918.
January	20·78	19·31	19·70	12·56	14·58	10·88	9·07	10·26	14·45
February	18·34	16·86	16·48	10·30	11·90	8·60	7·86	9·46	9·40
March	17·28	15·29	15·47	9·19	10·81	8·48	5·46	8·58	10·46
April	11·89	10·27	10·47	6·01	8·27	5·27	3·93	6·17	5·84
May	7·79	7·14	7·36	3·72	5·35	3·45	2·22	3·66	4·85
June	5·12	4·70	4·72	2·49	4·36	2·36	2·13	1·86	1·90
July	5·11	4·94	4·75	2·39	5·01	1·76	1·83	2·35	1·76
August	6·75	6·63	5·98	3·45	6·41	2·70	2·24	2·73	2·57
September	9·76	9·58	9·97	5·34	7·48	7·53	2·58	2·99	4·08
October	13·78	13·48	14·22	7·54	10·04	8·31	3·88	5·11	6·14
November	16·54	16·60	16·81	10·03	8·28 ?	9·52	6·48	7·94	10·84
December	20·31	19·75	19·80	12·64	13·41	10·94	8·28	10·65	14·46

Average Yearly.

	153·45	144·63	145·73	85·75	114·35	79·82	56·83	78·24	80·73

Maximum Daily and Monthly.

Day	1·26	1·00	1·20	1·25	0·84	0·60	0·47	0·57	0·872
Month	25·00	25·48	24·02	17·85	15·51	10·94	9·96	10·65	14·46
	12	12	11	18	14	1	1	1	1

TABLE 4.

Mean Monthly and Annual Rainfalls at Capitals and Principal Towns in the Commonwealth.

City.	Latitude.	Longitude.	Height.	Distance from Coast.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
	S.	E.	Feet.	Miles.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Port Darwin ...	12° 28′	130° 51′	97	...	15·27	13·05	9·70	4·50	0·75	0·16	0·07	0·11	0·48	2·12	5·21	10·30	61·72
Broome ...	17° 57′	122° 15′	34	...	4·96	6·35	3·77	1·35	0·41	1·22	0·27	0·04	0·08	0·03	0·93	3·55	22·96
Perth	31° 57′	115° 51′	197	12	0·33	0·31	0·71	1·65	4·88	6·51	6·44	5·55	3·37	2·06	0·76	0·54	33·11
Kalgoorlie (Coolgardie)	30° 45′	121° 30′	1,261	387	0·33	0·61	0·82	0·69	1·41	1·18	0·92	0·93	0·55	0·79	0·45	0·59	9·27
Alice Springs ...	23° 38′	133° 37′	1,926	576	1·68	1·73	1·24	0·90	0·60	0·57	0·46	0·40	0·41	0·72	0·90	1·32	10·93
Adelaide ...	34° 56′	138° 35′	140	6	0·74	0·60	1·07	1·88	2·77	3·09	2·66	2·51	1·94	1·75	1·13	0·94	21·08
Broken Hill ...	30° 58′	141° 21′	1,001	220	0·79	0·81	0·63	0·75	0·91	1·22	0·65	0·98	0·69	0·84	0·59	0·79	9·65
Bendigo ...	36° 46′	144° 17′	825	73	1·37	1·04	1·55	1·67	2·12	2·73	2·01	2·21	2·05	2·04	1·52	1·19	21·50
Ballarat ...	37° 33′	143° 52′	1,430	46	1·70	1·34	2·01	2·46	2·92	3·10	2·59	2·86	2·94	2·76	2·26	1·82	28·76
Geelong ...	38° 10′	144° 21′	90	1	1·34	1·24	1·63	1·83	1·96	2·03	1·49	1·60	1·89	1·84	1·68	1·19	19·72
Melbourne ...	37° 50′	144° 59′	115	3	1·85	1·74	2·18	2·32	2·15	2·11	1·86	1·81	2·35	2·64	2·20	2·30	25·51
Hobart	42° 53′	147° 22′	160	1	1·80	1·45	1·65	1·80	1·91	2·22	2·10	1·83	2·14	2·24	2·50	1·93	23·57
Launceston ...	41° 27′	147° 10′	33	32	1·96	1·10	1·85	2·07	2·54	3·45	2·99	2·77	2·97	2·61	1·81	2·04	28·16
Canberra ...	35° 20′	149° 15′	1,910	60	2·46	1·78	1·97	1·63	1·69	1·94	1·31	1·53	1·80	2·28	2·20	2·06	22·65
Bulli (Wollongong)	34° 25′	150° 56′	33	...	4·04	4·94	4·14	4·92	3·86	4·59	3·26	2·77	2·77	2·77	2·69	2·90	43·65
Sydney	33° 52′	151° 12′	146	5	3·67	4·70	5·07	5·24	4·95	5·18	4·68	3·29	2·89	2·82	2·91	2·60	48·00
Newcastle ...	32° 55′	151° 49′	112	1	3·50	4·60	5·46	4·42	4·83	4·17	4·44	3·42	3·26	2·98	2·87	3·23	47·18
Maitland ...	32° 45′	151° 35′	19	18	3·23	3·64	3·94	2·72	2·45	2·52	2·67	2·42	2·66	2·27	2·42	2·84	33·78
Brisbane ...	27° 28′	153° 2′	137	10	6·66	6·63	6·20	3·64	2·92	2·62	2·33	2·35	2·05	2·78	3·65	5·12	46·95
Rockhampton ...	23° 24′	150° 30′	37	18	9·26	8·36	5·43	2·44	1·63	2·03	1·63	1·01	1·38	1·72	2·17	4·04	41·10
Thursday Island	10° 34′	142° 12′	17	...	18·15	17·29	14·36	8·01	1·65	0·47	0·30	0·22	0·10	0·29	1·29	5·76	67·89

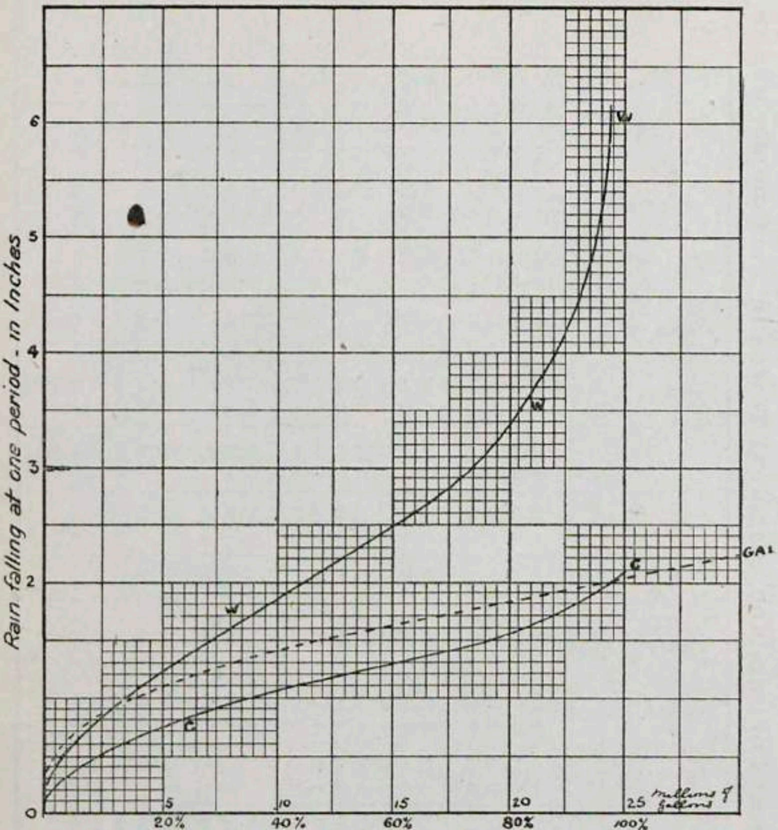


DIAGRAM 1.
Small inland catchment areas in Western Australia, illustrating a method of determining off-flow.

Explanation—
W=Ratio of off-flow to rainfall on total catchment area.
Gals=Total off-flow in gallons.
C=Ratio of effective catchment area to total area.

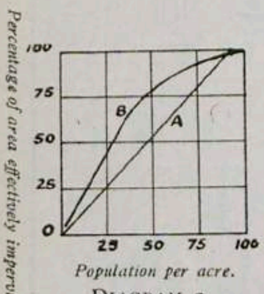


DIAGRAM 2.
A. Storms of short duration
B. Storms of long duration

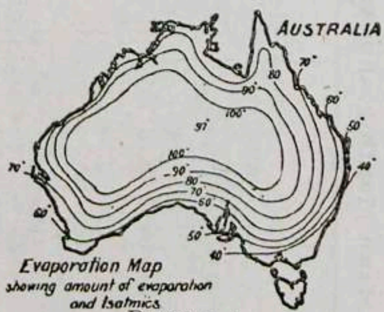


DIAGRAM 5.

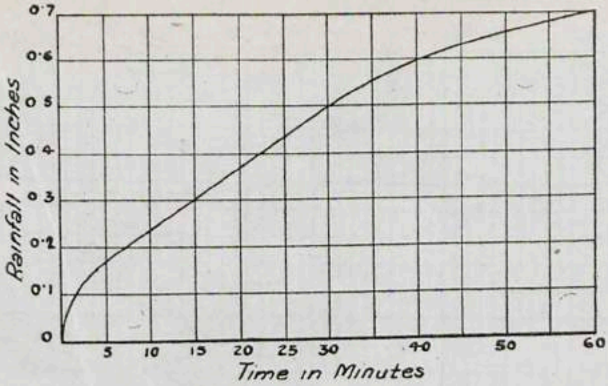


DIAGRAM 3.

Rainfall intensity recorded at Edgbaston Observatory Oct. 13, 1900 to Oct. 13, 1904.

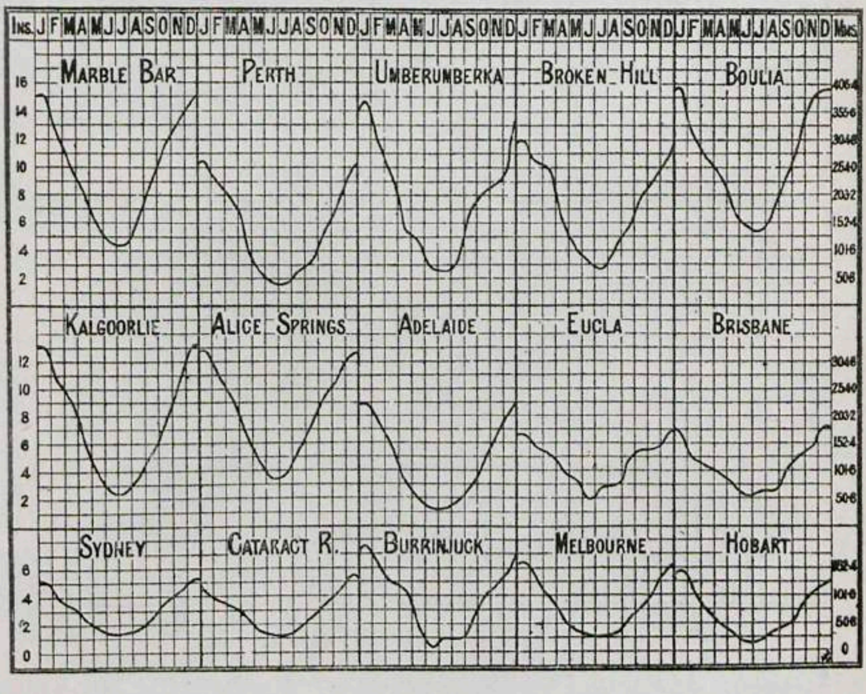


DIAGRAM 4

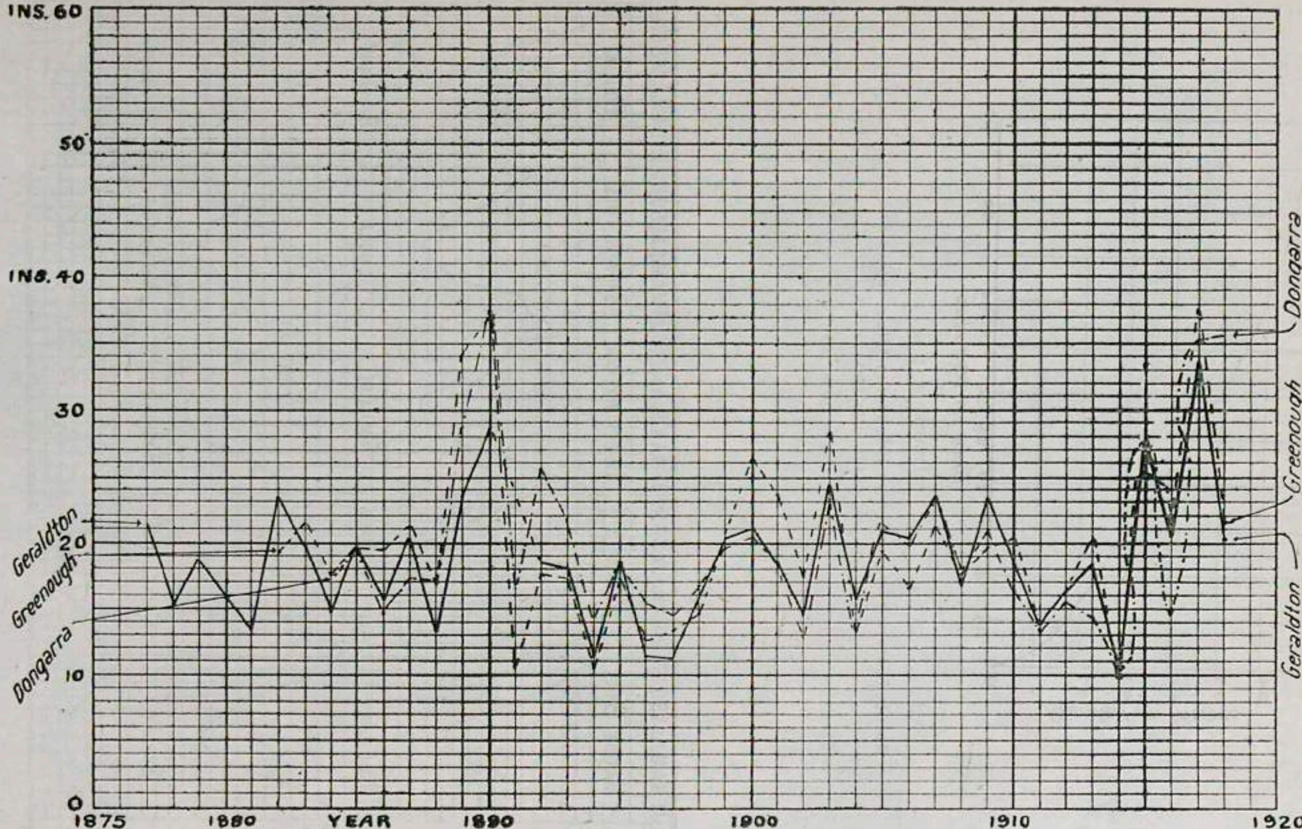
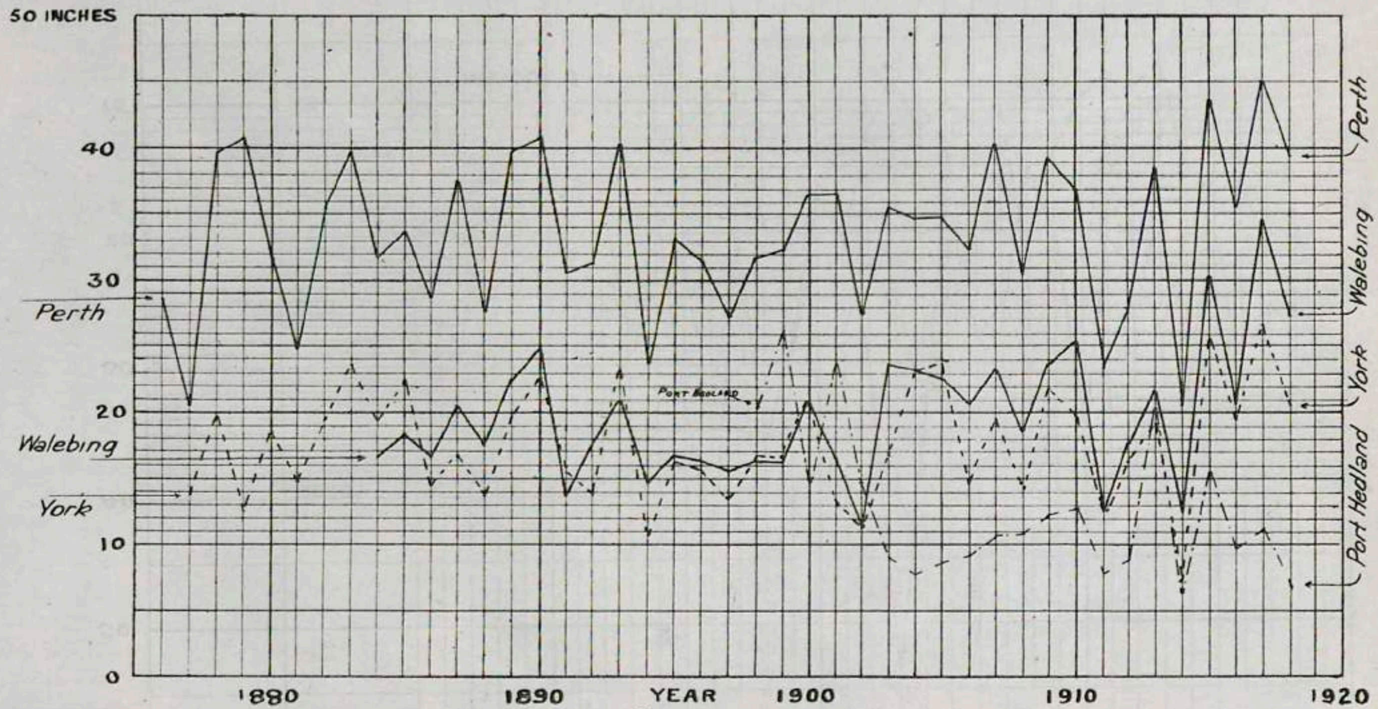

INS. 60
50
INS. 40
30
20
10
0
1875
1880
YEAR
1890
1900
1910
1920
Geraldton
Greenough
Dongarra
Dongarra
Greenough
Geraldton

DIAGRAM 6.


50 INCHES
40
30
20
10
0
Perth
Walebing
York
Port Hedland
1880
1890
YEAR
1900
1910
1920
DIAGRAM 7.

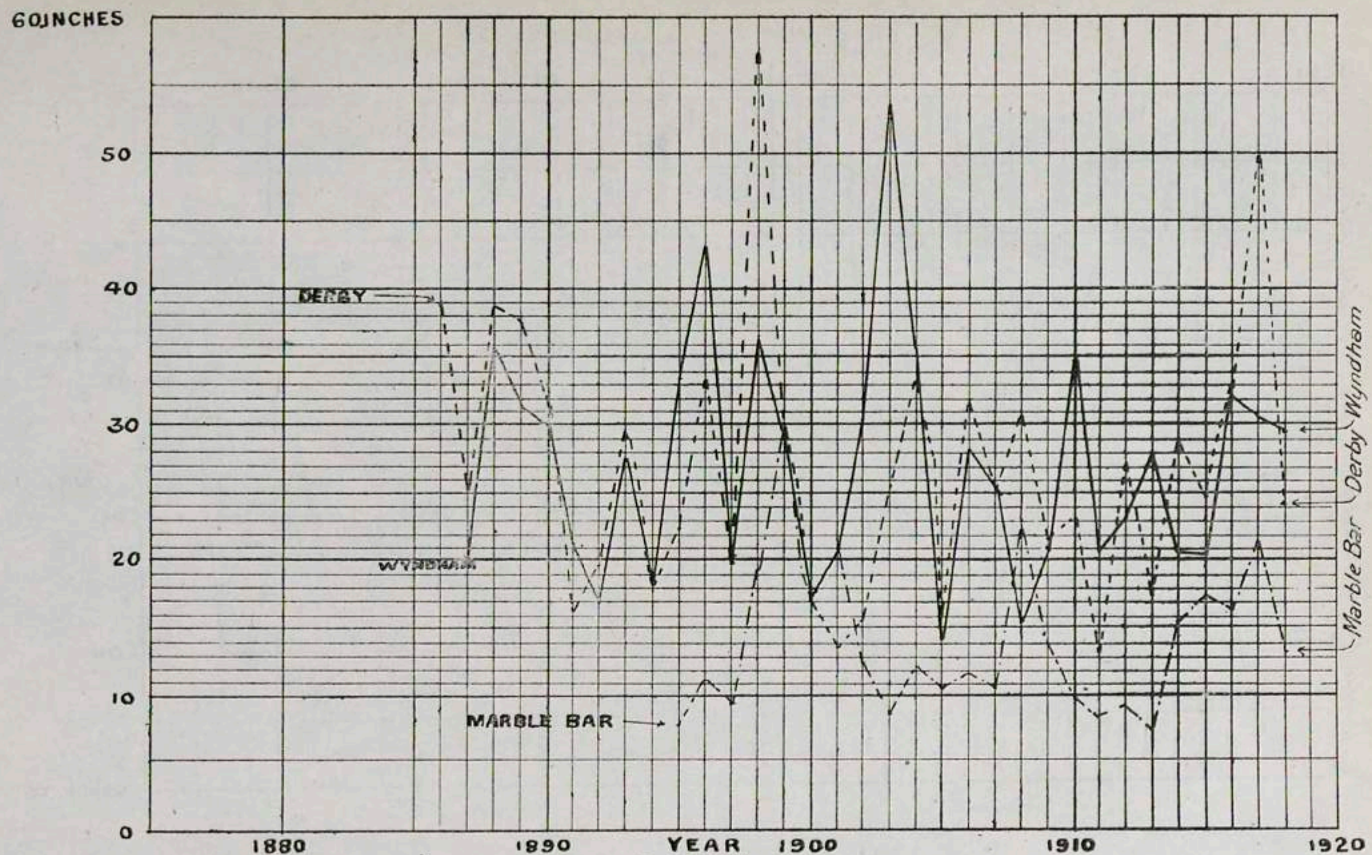

60 INCHES
50
40
30
20
10
0
1880
1890
YEAR
1900
1910
1920
DERBY
WYNDHAM
MARBLE BAR
Wyndham
Derby
Marble Bar

DIAGRAM 8.

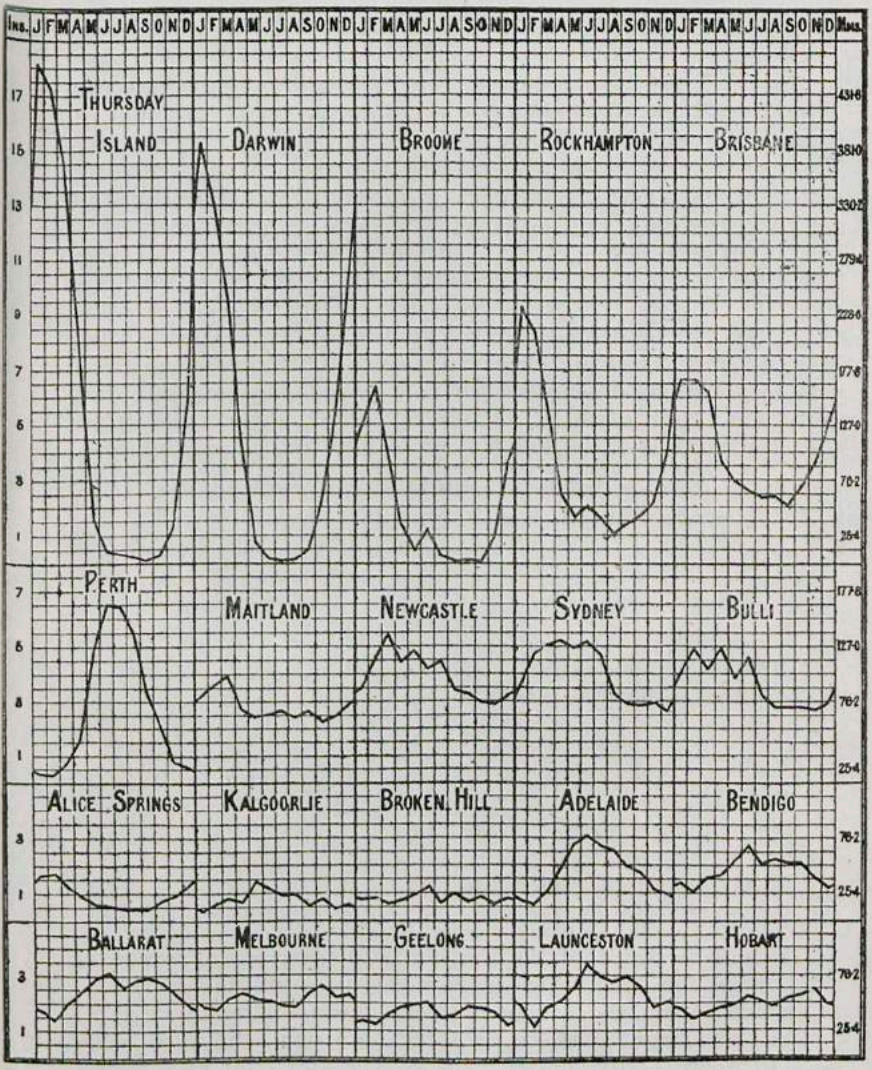

Ins.
Mms.
Thursday Island
Darwin
Broome
Rockhampton
Brisbane
Perth
Maitland
Newcastle
Sydney
Bulli
Alice Springs
Kalgoorlie
Broken Hill
Adelaide
Bendigo
Ballarat
Melbourne
Geelong
Launceston
Hobart

Diagram 9.

RAINFALLS AND RUN-OFF FROM CATCHMENT AREAS.

DISCUSSION.

Mr. J. Parr said:—The scarcity of rainfall data referred to by Mr. Shields, is characteristic not only of Australia, but of the world generally. There are very few records of rainfalls in any part of the world over lengthy periods. Dealing recently with this question, one modern authority states that rainfall records extending much above 50 years are somewhat rare. In spite of this, however, Sir Alexander Binnie many years ago formulated certain general rules from the data then available and gave them in a paper to the Inst. Civil Engineers in 1891. (Vol. 109). These rules were referred to by Mr. Shields. They have stood the test of experience since 1891 and have been shown by various observers to have a remarkably accurate and world-wide application. The following table shows these rules, and also shows how the Perth records compare therewith.

Table showing ratios of rainfalls for wet and dry years to the average rainfall over a long period:—

	World Average.		Perth.
	over 20 in.	under 20 in.	
No. of Stations	140	13	
Wettest Year	1.49	1.75	1.36
Average 2 Wetest Years	1.32	1.49	1.26
„ 3 „ „	1.26	1.37	1.21
„ 3 Dryest Years	.76	.67	.84
„ 2 „ „	.70	.62	.72
Dryest Year	.61	.51	.59
Maximum Number of Years Consecutive above average	5.11	5.62	4.00
Maximum Number of Years Consecutive below average	5.73	7.38	6.00

It will be seen that the Perth records correspond generally with those for the world average. In computing the above ratios for Perth, the average rainfall has been taken at 34.23 inches. The recorded average rainfall for Perth (*i.e.*, since 1876) is 33.67 inches only, but as will be explained later, a longer period will probably show a higher average up to 34.23 inches. For a longer period also, it is apparent that the ratios for Perth will still more closely approach the general world average thân as shown in the table. It will be seen also from Mr. Shields' table "Rainfalls in Western Australia," that the maximum and minimum ratios to mean for the bulk of the stations in the

temperate area, are again in close agreement with the general rules and it is probable that many of the irregularities may be due to the series of records being too short to give a true mean, rather than to any departure from the rules. The rules are found generally to apply to insular climates, but do not generally apply to inland continental dry climates, where there are frequent cases of years with no rainfall, or to places that lie geographically between regions of markedly lower and higher absolute rainfalls. They would appear to apply generally to our State along the coast south from the Murchison and throughout the agricultural areas, and can thus be made use of in dealing with rainfall data in this area with reasonable safety. The diagrams (6 to 8) given by Mr. Shields, showing the rainfalls at various stations in this State, are particularly interesting and valuable. They are valuable because they give in a graphic form a vast amount of data, at all times ready for reference, and interesting because they show a remarkable similarity in the behaviour of the rainfall at the various station at long distances apart throughout the temperate parts of the State. This remarkable similarity is, no doubt, due to the absence of any disturbing physical features such as high mountains. From a consideration of these diagrams, it is apparent that yearly rainfalls at intermediate stations could be interpolated, after a few are known to give a starting point, or in continuing a rainfall record at a place where records have been taken for a number of years, but where a longer estimate of rainfall is desired—the estimates being taken from the records of suitable adjoining stations by multiplying them by the ratio found to exist between the rainfalls for known years. Taking a wider range in Fig. 1 hereunder, the rainfalls for Perth and Adelaide are plotted in the same manner as those by Mr. Shields, and it will be seen that here also there is a remarkably close connection. Records have been taken at Adelaide since 1840 and at Perth since 1876. The average rainfall for Adelaide between 1876 and 1917 is 20.61 inches, and for Perth 33.52. The average rainfall for Adelaide 1840 to 1917 is 21.05, and as the diagrams show that the rainfalls at Perth and Adelaide vary correspondingly, the mean for Perth over the period 1840 to 1917 may accordingly be taken as 34.23 inches. With regard to the question of indications of periodic laws, referred to at the conclusion of Mr. Shields' paper, it is apparent, as Mr. Shields states, that the period over which records have been taken in this State is too short to warrant any attempt to derive periodical laws therefrom. The question has, however, been recently dealt with in a most interesting paper contributed by Mr. T. W. Keele, M. Inst. C.E., of Sydney, to the Inst. Civil Engineers (Vol. 202), entitled "Investigation of the Nile River Flood Records for traces of Periodicity." Mr. Keele was led from the observed decline in the Rainfall in New South Wales

from 1893 to 1902, to inquire if the available records showed other similar long periods of rainfall below the average—not only in New South Wales, but in other parts of the world as well. He found that in New South Wales from 1845 to 1859 (14 years) there were only three years above the average. He also found later that the drought 1893 to 1902 continued to 1912—a total of 19 years from 1893, with only 3 years above the mean. In the course of his inquiries, Mr. Keele obtained long date records from Greenwich (1726 to 1913), Padua (1741 to 1817), and the Nile Flood records from A.D. 640 to 1451 and from 1825 to 1913. To facilitate consideration of the data, "Residual Mass Curves" were computed and plotted therefrom. The "Residual Mass Curve" is a most useful means for showing variations of rainfall over extended periods—or wet and dry periods. Figure 2 shows the residual mass curves for the rainfalls at Perth and Adelaide respectively. The curve represents the summation of the differences between the average rainfall over a long period and the actual rainfall for each year. Thus for Adelaide the average rainfall, 1840 to 1917 is 21.05 inches. For the year 1880 the rainfall at Adelaide was 22.48 inches, or 1.43 inches above the average. The curve, therefore, shows a rise of 1.43 inches for the year 1880. For the year 1881 the rainfall at Adelaide was 18.02 inches or 3.03 inches below the average. The mass curve, therefore, shows a decrease or fall of 3.03 inches for the year 1881. A horizontal line in the curve thus indicates neither a rise nor a fall—*i.e.* it represents the average rainfall. A rising line indicates rainfall above the average, and a falling line, rainfall below the average. Thus from the diagram it will be seen that from 1846 to 1864 was a period of heavy rainfall in Adelaide, with only five years below the average, and from 1895 to 1902 was a period of dry years, with only one year slightly above the average. The residual mass curve is such as would be produced by plotting the rise and fall of a lake which has no outlet, and which, therefore, has practically a uniform quantity drawn from it each year by evaporation. It may also be taken to roughly correspond with the rise and fall of the subsoil water that may be expected during periods of wet and dry years. Figure 3 is a reproduction of a residual mass curve, plotted by Mr. Keele from the Nile Flood records. Having plotted this curve and finding no traces of periodicity of 11, 13 or 33 years, it occurred to Mr. Keele to test the accuracy of the records by reference to chronological events, and he found that the great droughts, rains and famines corresponded very fairly with the records, and also that the dates of several appearances of Halley's Comet synchronised with the greatest declines shown in the residual mass curve, which, of course, denotes the longest periods of drought. The average period between the appearances of Halley's Comet is about 76 years, and the diagram is plotted, showing the periods

of 76 years, dating back from 1893, which was the crest of the rainfall curve for Sydney. Mr. Keele concludes: "Although it cannot be claimed from the results that there is an exact agreement with a 76 year period, it will be seen that the conformation of the crests of the curve with that period is very remarkable. The curve shows that the greatest decline of modern times, which has existed for the last 15 years over the drainage area of the Nile, and which has also been shown to be probably universal in varying intensity, according to local conditions, has been repeated at intervals of about 76 years, with more or less intensity, so far back into the past as A.D. 640." Mr. Keele considers, therefore, with good grounds, that in order to determine the true mean rainfall at any place, it is necessary to have a continuous record there for a period of not less than 76 years, and that anything less than this is liable to result in a more or less incorrect estimate of the mean. It may be possible for a decline to last 30, 40 or 50 years, in which case the means for these years would lead to a very incorrect appreciation of the true conditions. Returning to the residual mass curves for Perth and Adelaide (Fig. 2), it will be seen that the period for which records have been taken at Adelaide is just long enough to give a mean for a 76 year period, and the average 21.05 may thus be taken as the true mean for Adelaide, and the corresponding average for Perth, 34.23, as determined above, may be taken as approximately the true mean for Perth. The residual mass curves (Fig. 2), like the rainfall curves (Fig. 1), show a remarkably close connection between the rainfalls of Perth and Adelaide. It will be seen also that a low point in the residual mass curve (1914) has just been passed, and the curve is now on an upward grade, that in ordinary course may fairly be expected to continue upward for some years, as in the period 1846 to 1864. In other words, the good rainfall years that have been experienced since 1914 are likely to be followed by further good rainfall years, such as are shown by the Adelaide curve for the period 1847 to 1864—when for a period of 17 years there were only five years below the average. If a mean line curve is run through the residual mass curve for the Adelaide rainfall, it will be found to have a period of about 76 years.

The residual mass curve appears to bring out prominently the reason for a striking phenomenon experienced in the Perth metropolitan area during the years 1915 to 1918, viz: a gradual rising of the level of the subsoil water and the water levels in the swamps and lakes between Bayswater and Claremont, and probably elsewhere. One reason that has been assigned to this rise is the clearing of land and the formation of roads; but this cannot account for the rise at Bayswater or Maylands, where such clearing and road making are inconsiderable. But a

reference to the residual mass curve will show that from 1890 to 1914 the rainfall was generally below the average, and from 1910 to 1914, very much below the average, so that it is to be expected there would be a gradual fall in the level of the subsoil water up to 1914, since when the rainfall having having been greatly above the average, a corresponding rise in the level of the water in the subsoil swamps and lakes is only to be expected. The question of salinity of the off-flows from catchment areas is of prime importance in this country and one which has not yet been thoroughly investigated. There are few countries in the world so badly off for water as Western Australia, and if by taking suitable measures it is possible to increase the off-flows from catchment areas, and at the same time reduce, or, at least, not increase the salinity; such measures would be of immense value to the State. At present, however, our knowledge of the salinity problem is not at all satisfactory. There are certain features about it that are well established and have been known for many years, such as (*a*) the bulk, if not all the salt in the off-flow waters from catchment areas near the coast, at least, comes from the air—salt spray from the ocean is carried up into the air, and carried inland either in the shape of small drops of salt water, or as vapour and salt dust that result from the evaporation of these drops of spray and are deposited inland; (*b*) the amount of salt so deposited annually diminishes in amount as the distance from the ocean increases. The decrease is so definite that equal amounts of chlorine are found along lines generally parallel to the coast. Figure 4 shows the distribution of salt in the surface water of the New England and New York States. The figures marked on the iso-chlors represent chlorine in parts per million of the water. It will be seen that the iso-chlors are parallel with the coast line. (*c*) Swamps on catchment areas not only reduce the off-flows by keeping back water during the wet season, but by intense evaporation in summer hold up large quantities of salt that are washed into the streams with the following winter's rains, and thus increase the salinity above what it would be if the swamps did not exist; (*d*) by draining swamps not only will the off-flow be increased, but the salinity reduced. It is possible that the whole solution of the salt problem lies in thoroughly examining the catchment area, for places where water is held either as swamps or damp patches, and the thorough draining of such areas so that no wet or damp surfaces will be left where evaporation can go on during the summer. There are many places in this country where springs begin to flow towards the end of the summer—before any winter rains have fallen. These springs would flow all through the summer, but for the fact that the evaporation is so great that all the water is evaporated as fast as it comes to the surface. It is only when the heat of the summer is passed, and evaporation diminishes

that the supply from undèrground becomes greater than the evaporation, and the spring begins to run. It is manifest that in such cases the accumulation of salt, due to the evaporation of the water during the heat of the summer, will cause the gronud about the spring to be salt, and also cause the water flowing from the springs to be salt for a considerable time after they begin to run. In many such cases it might be possible to get a supply of good fresh water throughout the summer by laying subsoil drains to tap and collect the water before it reaches the surface and so conduct it to the tanks for stock or domestic use. It is generally accepted in this country that clearing a catchment area will turn or tend to turn the off-flow water salt. There are, however, cases where clearing has improved the off-flow and has not made the water salt. The actual position may thus, perhaps, be more correctly stated by saying that in many cases, but not in all, the clearing of a catchment area has caused previously fresh water streams to turn salt. That clearing a catchment area will improve the off-flow can be taken as an established and accepted fact—but under what conditions such clearing will cause a fresh stream to turn salt, is a question that has not yet been solved, nor has any reasonable explanation been published why a fresh stream should turn salt under such conditions. On the other hand, seeing that clearing will improve the off-flow, and as there is no increase in the quantity of salt brought on to the catchment area, and at the same time the same amount is taken off each year as goes on to it, there appears good grounds for expecting that the salinity would rather decrease after clearing. It is impossible for the trees to hold up any great amount of salt in their trunks, branches and leaves. This is proved by the analysis of the wood ash. It is not, therefore, from the wood ashes or the decay of the wood or leaves that the salt comes after clearing. During the life of a tree, water is taken from the soil by the roots, is forced up to the leaves, and there evaporated. If the water taken up by the roots and forced up to the leaves and there evaporated, was of the same constitution as the subsoil moisture, it is clear that there would be a large accumulation of salt in the leaves. This is not the case. The position is that the concentration of salt in the sap reaches a certain amount, and does not vary greatly from that amount for any particular timber. The concentration of salt at the leaves is probably greater than at the roots, and there is (due to osmosis) steady a flow of salt from the leaves to the roots, just as there is a steady flow of water from the roots to the leaves—the net result being a practically constant amount of salt in the tree. The concentration of salt must thus take place in the soil at the roots of the tree, and there will be a large amount of comparatively salt water held up, as in a sponge, by the fibrous roots of the trees. When the trees are killed or cleared away, the

accumulation of salt water so formed will be gradually leached away and so make the streams from the catchment area comparatively salt till such time as the whole of the salt water has disappeared, when the stream should be carrying off each year only just as much salt as is brought to it by the wind and rain each year. The stream should thus return to its original degree of freshness, and should even become more fresh according to the increase in the off-flow following on the clearing. The absolute quantity of salt carried to a catchment area every year will vary greatly with the distance from the coast. Isolated figures are, therefore, of little use for comparison of the quantities falling in different countries. The following table gives the quantity of sodium chloride brought to the surface of the earth each year at various places in pounds per acre (26 years' average) :—

	Lbs.
Cirencester (England)	36.10
Rothamsted (England)	24.00
Perugia (Italy)	37.95
British Guiana	195.00
Leederville (West Australia)	135.00
Mundaring (West Australia)	58.00

It is thus apparent that huge quantities of sea salt are carried inland every year from the sea, and it is equally apparent that on the average the same quantities must be carried back to the sea year by year.

Such are the salient features of the salinity question. To solve the question it is first necessary to ascertain why a catchment should shed salt water after clearing, and the way would then be open to determine under what conditions a catchment area may be cleared to advantage. It is a question of very great importance to the State, and it behoves Water Supply Engineers to give it most careful study and investigation.

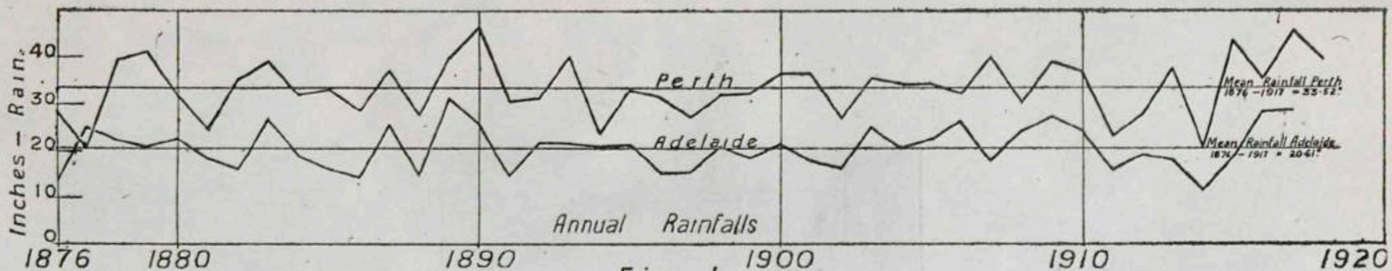


Fig. 1

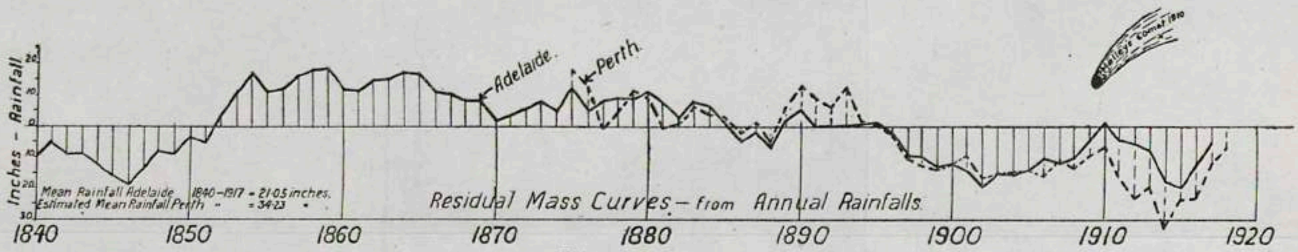
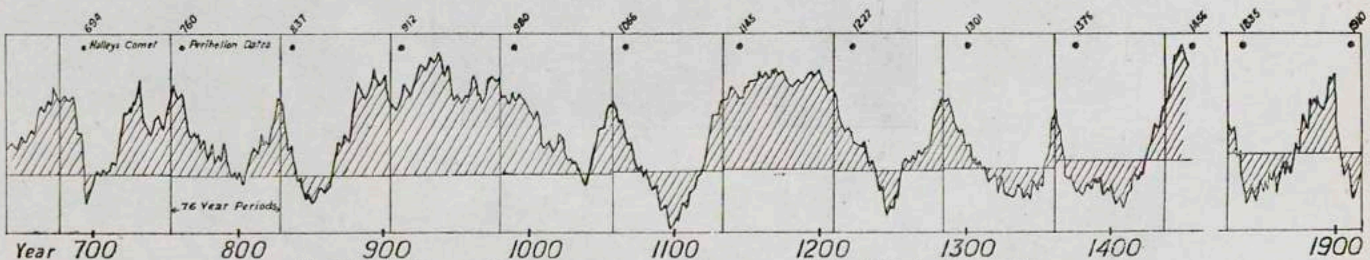


Fig. 2



Residual Mass Curve Nile Flood Records.

Fig. 3.

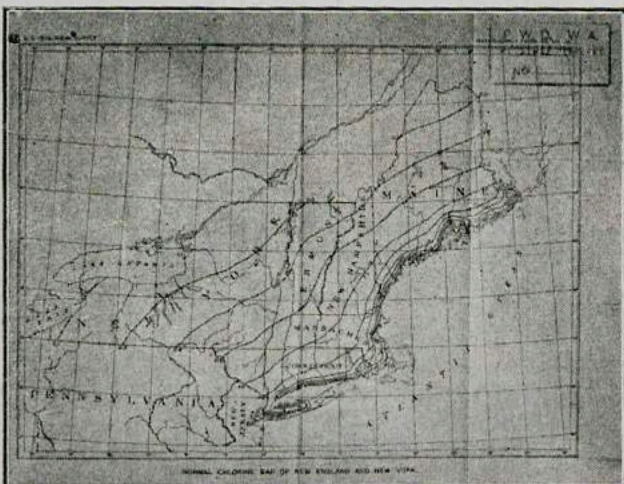


FIG. 4.

Mr. Shields, in replying to Mr. Parr and Mr. Crocker, said that Mr. Parr's diagrams of the Nile flow, and salt blown inland from the sea were most interesting. It was probable that, besides what was blown inland from the sea, a great deal of salt was liberated by the decomposition of rocks. Although the Conservator of Forests stated some time ago that salt was not present in the texture or sap of jarrah, there are plants that have quite a considerable quantity of it, and it is used as a manure for beet-root, sea-kale and some other plants. Moreover, the ash of timber was rich in soda, and it was quite possible that this soda entered the roots as salt. In Western Australia there were many brine springs compared with the total number of springs. In some districts it was difficult to find a likely valley for conserving water quite free from them. In one case where a reservoir was proposed a number of small brine springs occurred, and he (the author) proposed to run a bank and ditch round the area and convey the water from it through an earthenware pipe, to discharge below the reservoir. In another site, off the Chapman river, a fresh water stream was abandoned, the author believes, needlessly, because in sinking trial shafts salt water was discovered below the clay. In some springs on the Murchison there was regular fire water, and again in other places there was free hydrochloric acid as in the salt lake where condensers were erected to condense water for engine purposes at Woolgangie. At another dam, water was struck at about 78 feet, rising about 50. It tasted like sour milk, and was used to make puddle, etc., but stock would not drink it. It is a common thing for wells in jam country to go salt when the trees have been ringbarked, but in some instances the author had known the well to recover when heavily drawn upon. It was very possible that to ringbark a gully would increase the flow of water from that gully, because eucalypts are very greedy drinkers, and are supposed to evaporate more water than most trees, ; but to ring-bark a large area would in all probability decrease the off-flow, for it is held to be proved that the precipitation was much heavier in forests than around them. Hence the great care bestowed upon forests by the Indian and other governments. The periods of great drought and excessive rain appeared to be world-wide, except in so far as they might be influenced by local conditions or thunder showers.

(SEPTEMBER 10, 1919.)

BRITISH INSPECTION OF STEEL IN AMERICA.

BY PROFESSOR H. E. WHITFELD.

1.—INTRODUCTORY.

One of the chief lessons of the War, as far as engineering practice is concerned, has been the necessity of standardisation in order to obtain quantity production. In obtaining this standardisation of product, an efficient and elastic system of inspection is of prime importance. In Great Britain it gradually became realised that a large staff of engineering and chemical experts was required to deal with the great munition programme instituted by the Ministry of Munitions in 1915 and men were drawn for the work from all parts of the British Empire. The approximate output of the principal kinds of munitions from August 4th, 1914 to November 11th, 1919, was recently stated by the Director of Inspection to have been as follows:—

1.	Field Guns and Howitzers (complete equipments)	35,000
2.	Trench Howitzers (or Mortars) (complete equipments)	19,209
3.	Machine Guns (complete equipments)	186,000
4.	Rifles (number)	5,050,000
5.	Steel Helmets (number)	7,500,000
6.	Empty Shell (gun and howitzer), principal natures (number)	257,000,000
7.	Filled Shell (sent overseas) (complete rounds)	197,000,000
8.	Trench Howitzer Ammunition (complete rounds)	13,156,725
9.	Small Arms Ammunition (complete rounds)	11,141,000,000
10.	Hand Grenades (number)	89,000,000
11.	Aerial Bombs (number)	4,175,000
12.	Fireworks, Signal Cartridges, Mortar Shells, Green Flares, Rockets, etc. (number)	100,000,000
13.	Propellants (tons)	463,000
14.	High Explosives (tons)	730,000
15.	Motor Transport—Lorries, Waggons, Ambulances, Tractors, Bicycles, Cars, etc. (number)	141,395
16.	Horse-drawn Vehicles—Waggons, Kitchens, Water Carts, etc. (number)	145,229

17. Optical Instruments (Principal), Binoculars, Clinometers, Compasses, Range Finders, Periscopes, Telescopes, etc. (number)	792,000

In addition to the above productions may be mentioned Mechanical Warfare Stores, which include tanks, liquid fire and gas apparatus, and other horrible engines of destruction.

To deal with this enormous production, a very large inspection staff was ultimately evolved. The branch of the department which was located in the United States and to which the author was attached, contained a staff of nearly a thousand. The actual evolution of the inspection department, proceeded on lines very similar to the change from the regular army of 1914 to the citizen army at the end of the war. The nucleus consisted of a small number of army officers and mechanics who had been trained at Woolwich before the War. The Admiralty had also an efficient staff of inspectors centred at Sheffield and added to their number by appointing to this work many retired naval officers, who, although they knew comparatively little about steel manufacture to begin with, nevertheless made excellent inspectors, thereby corroborating Palmerston's statement "When I want a man with a good head, a good heart, lots of pluck and plenty of common sense, I always send for a captain of the Navy." These two organisations were used to train a great body of civilian engineers and chemists, and gradually the military officers were relegated to special positions where their long training was particularly required. The author of this paper entered the service of the Ministry of Munitions in March, 1916, as an Assistant Inspector of Steel, was trained by the Admiralty at Sheffield and Middlesborough and sent to the U.S.A in May of the same year and stationed at Pittsburgh, under Colonel (then Major) Lyddon.

2.—General Conditions in the U.S.A.

In the United States in the early stages of the War there was first of all a stagnation of trade, owing to the general upheaval and disorganisation in the financial world. Early in 1915, the Allies began to realise that they could not produce themselves all the munitions required and to place orders in a desultory and haphazard fashion in the United States. Contracts were sometimes taken by firms which had little ability or intention to fulfil them, and it was not until the British Government placed all their buying in the hands of J. P. Morgan and Co., that things were established on a sound basis. This firm was able to give valuable advice as to the reliability and experience of the various manufacturers, and although there continued to be some cases of failure to fulfil a contract, in most

cases the American firms did their best to give us a satisfactory article within the specified time. The chief thing to complain about was the price, which was a good deal higher than the cost of manufacture in England. Thus American T.N.T. in 1916, cost us a dollar a pound and half a dollar in 1917, whereas, at Queensferry, in England, it cost subsequently only 8½d. to manufacture. An 18 pounder shell cost over a pound or nearly double the price paid in England. In justice to the American firms, it must be pointed out, however, that they were new to the work and often lost a lot of time before they could produce the specified article, that they had to instal special plant, which might only be used for a short period, and that they were liable to alienate the sympathy of a number of their skilled workmen of German or Austrian origin. One of the big steel firms told the author that out of their 60,000 employees, over 30,000 were of Austrian or German origin.

3.—General Organisation of Inspection.

The essential point about an inspection department is that it shall be independent of the production department, and be only directly concerned with seeing that the goods supplied fulfil the specifications and are properly marked for identification. At the same time, it is important that the inspectors should work in harmony with the officers responsible for production and should be able to advise them and the manufacturers as to improvements in the methods of manufacture. Frequently, too, the inspection department can give valuable advice to the contracts department, by suggesting alterations in the designs and specifications, for it usually happens, that a part that is difficult to inspect, is unreliable when produced, and can be designed in some simpler form. The inspection in U.S.A. was under a director (General Kenyon), who, in turn, was responsible to the Director of Munitions in England (Mr. A. H. Collinson), who was responsible only to the Minister of Munitions.

The actual procedure in a particular case would be as follows:—The Inspection Department would be notified by Messrs. J. P. Morgan that a contract (a copy of which was attached) had been placed with a certain firm. The Inspection Department would then write to the firm outlining the proposed method of inspection under the contract, and asking when they intended to begin manufacture. On receipt of this information, the Inspection Department would place examiners at the firm's works to carry out the routine inspection and arrange for periodical visits as required from inspectors. The head examiner was responsible for the carrying out of such operations as sampling, gauging and marking material which was within specification. He had no authority to accept material outside specification,

whereas the visiting inspector had certain limited tolerances which he could allow. Beyond these he could only reject the material outright, or order the defects to be remedied, or refer to headquarters, in cases of doubt.

4.—Desiderata in Shell Steel.

Most of the steel bought in America for the British Government, consisted of shell steel, and to this the paper will chiefly refer. It was shipped to England, either as a finished shell (unfilled) or rough forgings, as multiple bars (*i.e.*, square, round, or gothic bars of a length suitable to make a definite number of shells), or as small ingots, or cast steel slugs, each of which would make one 6 inch, 8 inch, 9.2 inch, or 12 inch shell. The relative prices were roughly as follows:—

Finished Shell (unfilled)	£80-£110	per ton
Rough Forgings	£30- £40	,,
Bars	£16- £20	,,

Shell steel is a medium carbon steel, which, in the case of high explosive shells, is not treated by quenching, but allowed to cool out slowly in the air or in the furnace. Shrapnel shell forgings, on the other hand, are quenched and tempered so as to develop the full strength of the material. The shrapnel shell carries only a small bursting charge, most of the weight is in the bullets. Consequently, it is designed with a thin wall of steel which must be as strong as possible. Even if a crack should develop in the quenching, it is unlikely that the charge of powder in the tin cup will burst the gun. The high explosive shell on the other hand, requires plenty of metal in any case, for shattering effect after the explosion and as the T.N.T. explosive has simply been melted and run into the shell, a crack in the wall of the shell is almost certain to lead to the wrecking of the gun. It is for this reason that the most important part of the inspection of high explosive shell steel is in the first stages of manufacture, *i.e.*, during the casting and fracturing of the ingots or bars, in order to make sure that the steel is free from piping, blowholes, segregation, or other defects, which may lead to some hidden crack or weakness. The same defects are no less dangerous in the engineering materials used in time of peace. It is quite irrational for us to accept engineering steels on the basis of a few physical tests, without knowing anything of the methods of casting, percentage of discard and similar details, for, unless the original piping and segregation have been cut away, the steel will have hidden cracks and weak patches, which may easily be missed in selecting physical tests, but are likely to lead to the failure of a structure. There is little doubt that many railway accidents have been caused from the sudden breaking of a

rail rolled from an ingot from which the whole of the piping and segregation had not been cropped.

5.—Inherent Defects in Steel due to Methods of Casting and Cooling Piping and Blowholes.

A mass of steel in cooling from a molten condition at about 1,500 degrees centigrade to ordinary temperature, will naturally contract about 5 or 6 per cent. by volume. The ingot cools from the outside inwards and therefore the tendency is to form a cavity in the interior, where the metal solidifies last. This cavity is called the pipe and occurs near the top of the ingot. The actual primary pipe or interior cavity in an ordinary commercial 8,000 lb. ingot is usually about 400 to 500 cubic inches (1.5 per cent of the volume.) This would be a vacuum if it were not for the gases, chiefly hydrogen and carbon monoxide, which are evolved by the cooling liquid, and which carry up molten steel towards the top of the ingot. This liberation of gases, while diminishing the pipe, causes the formation of blowholes in the steel. The evolution of gases is lessened by the presence of aluminium, silicon, manganese, titanium and other deoxidisers. Brinell (Journal of Iron and Steel Institute, 1902, No.I), tried to establish a quantitative relation between the elements Al, Si and Mn and also to establish the fact that certain definite ingot types showing piping and blowholes, respectively, might be expected with definite quantities of the above elements present in the steel at casting. In Figure I, are shown certain of Brinell's ingot types. Brinell's "Density Quotient" is the factor Mn plus 5.2 Si plus 90 Al. The most satisfactory type of ingot (No. 5 of the series), was obtained when the "Density Quotient" was 1.66 for 10 inch ingots or 2.05 for 14 inch ingots. The actual effect of the deoxidisers seems to be twofold. In the first place, such elements as Si, Al, etc., seem to keep the gases in the steel as solid solutions (cf. Baker, Iron and Steel Institute, C. S. M., 1909, 1911) and secondly they have a direct action on the oxygen, ferrous-oxide etc., which may be in solution in the steel and they tend to prevent the violent evolution of carbon monoxide from a "wild" heat. Boylston (Iron and Steel Institute, 1916), found that Al and ferro-silicon produced a pipe, but few, if any, blowholes; whilst ferro-titanium and ferro-manganese produced many blowholes, but little, if any, pipe. Most of the American shell steel contained about 0.60-0.80 Mn and 0.25 Si, and the majority of the firms used, say, 5 ozs. of aluminium per ton added to metal. This would give a Brinell factor of over 3, including the aluminium and produced a piping steel. Without the aluminium the Brinell factor would be 1.80-2.20 and the steel would probably be a blowhole type since the American firms use large ingots (about 20 inch). For

a certain chemical composition the tendency to form pipe rather than blowholes increases with the casting temperature, and decreases with the size of mould. Probably, the greater part of the steel which we inspected, was piping steel, but many steel firms avoid trouble with pipe by casting and rolling ingots of type 7-9. These contain originally a number of fairly deep-seated blowholes, which are supposed to weld up in rolling. The steel is less dense than a piped ingot and is, therefore, easier to roll and to heat. The gases in blowholes are chiefly hydrogen and monoxide. Nitrogen, oxygen, methane and carbon-dioxide are less than 2½ per cent. of the total gases. The action of the gases on the walls of the blowhole is therefore usually a reducing action, but even so, it is very doubtful whether the blowhole will weld up completely and be as solid as the other portions of the ingot. Should the walls of a blowhole become oxidised, they would not weld together. Stead has shown that liquid segregates with high percentages of impurities sometimes collect in blowholes. (Cleveland Institute of Engineers.)

Position of Pipe in the Ingot.—More important than the size of the pipe is its position in the ingot, and here the common American practice of casting ingots with the big end down is markedly inferior to the usual British practice of casting with the big end up. Fig. 2 shows Brearley's diagram (J. I. and S. Inst., 1916, No. 2), illustrating the cooling of the layers in the two cases, and the way the pipe is thrown down into the lower part of the ingot cast with its big end down. Bottom casting also tends to lower the pipe, and does not seem to be generally desirable. It is used by some American firms, but is not the usual practice. Anything that tends to make the ingot cool from the bottom upwards and freeze last at the top helps to raise the pipe. Slow casting has this effect, and one way of bringing this about is multiple pouring, *i.e.*, the steel runs from the ladle into a basket suspended beneath it and from this two or four moulds are filled simultaneously. Another method of raising the pipe is to use a hot-top or sand-ring at the top of the mould, so that the top will freeze last. An extended application of the same idea is Hadfield's process, in which he keeps the top molten by adding a little slag and some charcoal, and applying an air blast.

Closing of Pipe and Blowholes by Compression.—The pipe can only be closed with any certainty if the ingot is compressed while the interior is still liquid. Talbot (J. I. and S. Inst., 1915) has recently introduced a process of cogging the ingot down whilst the centre is still liquid. In this process the segregated portion is found to be displaced from its normal position and distributed into a ring between the outer walls and the central axis. There seems to be little doubt that some American firms

also roll while the interior is still more or less liquid, for we found similar segregated rings in many cases (cf. Fig. 3).

Other Defects in Ingots.—Segregation is caused by the fact that the carbides, sulphides, and phosphides of iron are more fusible than the average of the steel, and tend to collect in the portion which solidifies last. Carbon probably segregates most in the first place, but is redistributed to some extent by transfusion through the red-hot metal. Sulphur and phosphorus are only slowly migratory. Ghost lines were originally segregated areas rich in carbon and phosphorus. As the metal cooled the carbon has migrated and been ejected by the phosphorus from the solid solution (austenite) as it approached the critical point, thus leaving a ferrite ghost rich in phosphorus, and this has been rolled out into a thin streak (v. Fig. 4). Segregation frequently accompanies pipe or blowholes, and although it occurred to some extent in American steel, most of the rejections were for piping, which was a more noticeable defect. Ghost lines were very plentiful in some steels and caused us a lot of trouble in those cases. They are only detected when machining begins, and are apt to result in minute cracks, as the phosphorus makes the metal more brittle along the streak. The fact that the American steel on the whole was not so sound as British steel was due largely to the rush and hurry of American production. Thus there was a tendency to kill the steel with aluminium instead of working it quiet in the furnace, to add the ferro-manganese to the ladle (causing slag inclusions (v. Fig. 5) and sometimes resulting in a very bad distribution of the manganese in the steel), to cast big end down so as to facilitate stripping, to pour too quickly, and to allow too little time in the soaking pits, thus causing a spongy structure from the rolling of the green ingots. On the other hand, the Americans argued that the steel was quite sound enough for the purpose for which it was required, and this was true in the great majority of cases, when the defective material, which is inevitable under our present methods of casting steel, had been eliminated by a rigid inspection. Even so, we would not infrequently come on very bad cases of secondary pipe when the shell was being machined (v. Figs. 6, 7 and 8).

6.—Inspection for Pipe, Blowholes and Segregation.

The unit of steel for inspection purposes was the heat or furnace charge. Each heat was given a code letter or letters and a number. The code letters were allotted according to the particular district, firm, contract, nature of shell, etc.; while the code number was a consecutive number given to each successive heat. As far as examination for pipe is concerned, each ingot was treated as suspect until it was found to be sound metal; but for chemical and physical tests the heat was con-

sidered as the unit. The specifications usually called for 20 per cent. discard from the top of the ingot. In England the usual practice is to allow the ingot to cool, then saw the discard nearly off, leaving 1-12th of the area to be fractured. These fractures are then examined for pipe and segregation, and if any such is found a fresh discard is cut from the particular ingots. Drillings for chemical analysis are taken on the fractured face at a point which is usually halfway between the centre and the outside. The cutting previous to fracture is sometimes done with an acetylene torch. Some U.S. firms tried using a ring-core, but this was found undesirable. The Admiralty specifications are much stricter. They call for 33 per cent. discard, 1-6th of the area to be left for fracture, and the drillings are taken from the centre of the fractured face. The American firms did not conform to this cold fracturing process except in the case of small ingots (cast steel slugs) made for individual shell. The American plants were designed for the ingots to be stripped and sent hot to the soaking pits and then to the rolling mills, and the 20 per cent. discard was then hot-sawn from the bars. This made the detection of pipe and segregation more difficult, as the defects were rolled out into the centre of the bars (v. Fig. 9). The bars were numbered so as to preserve their position in the ingot, and the top next to the discard point was cold fractured. If pipe and segregation was observed then more fractures were made down the bars until sound metal was met with. A certain percentage of fractures were also made in bars lower down the ingot so as to look for secondary pipe or other defects.

7.—Inspection for Chemical Analysis.

Drillings were taken from a fractured face (next to the discard) at a point on the cross section halfway between the centre and outside. Half of these drillings were analysed by the firm, and the other half sent to the inspection office and checked in our chemical laboratory. The firm made a full analysis for carbon, manganese, silicon, sulphur and phosphorus, and the inspection department laboratory usually checked the carbon and one or more of the other elements. We frequently made over a hundred carbon determinations a day, and by using the Fleming bulb, two chemists had no difficulty in doing this work with two electric combustion furnaces.

The usual specification limits, methods of analysis, etc., were as follows:—

Carbon.—Usually specified 0.40 to 0.55 per cent. A variation of, say, 8 points (0.08 per cent.) in different parts of the same ingot is frequently found, quite apart from the segregated area near the pipe, where the carbon may be double the average.

The combustion method of analysis was always used, catching the CO_2 in soda lime: this is accurate to 1 or 2 points (0.02 per cent.). The calorimetric method is not accurate enough. If the carbon fell below 0.42 per cent. there was usually difficulty in getting the steel to give the specified yield-load in physical test (19 tons), while if it exceeded, say, 0.60 it would possibly fail in elongation and might be on the hard side for machining. In one or two cases when a heat of about 0.65 carbon managed to get through owing to some mistake, we had a loud cry of woe from the machining firm whose work was set for softer steel and whose output of shells was badly crippled for the time.

Manganese.—Specified as 0.40 to 1.0 per cent., but we usually tried to get the firms to keep it at about 0.80, as it undoubtedly improves the quality. At first the American firms were apt to suspect ulterior motives in this, as ferro-manganese went up to 400 dollars a ton, and was largely controlled by Great Britain; however, they found that it paid to keep the manganese up. The distribution of manganese in steel is usually very uniform, but in one or two exceptional cases we found manganese varying from 0.60 to 2.0 per cent. in a heat, this being due to bad mixing in the ladle. The method of analysis used was usually the ammonium persulphate method.

Silicon.—Specified usually as 0.10 to 0.35 per cent. When the silicon was low we usually suspected a blowhole steel, and specified three compression tests. The idea was that the blowholes would roll out into minute cracks, and that these would open up in the compression test. Actually, the American steel very rarely failed in this way. The usual methods of analysis were Drown's or nitro-sulphuric acid conversion to SiO_2, and weighing. It is the most tedious of any of the ordinary determinations for steel.

Sulphur.—Specified limit was at first 0.05 per cent., and afterwards 0.06 per cent. The injurious effects of sulphur depend on the percentage of manganese, as manganese sulphide is much less injurious in the steel than iron sulphide, which produces red-shortness. In shell steel the ratio of Mn to S was usually at least 10 to 1. The chief danger is that the sulphide may collect in blowholes or other centres and form weak points from which a crack will start. In cases of doubt as to the distribution of sulphur it was usual to take a sulphur print. This is done by making a fairly smooth surface and applying to it a sheet of ordinary silver bromide printing paper which has been soaked in dilute sulphuric acid or hydrochloric acid. The blackened spots on the paper indicate the occurrrence, of sulphides (v. Figs. 10 and 11). The ordinary method of analysis was evolution as H_2S and titration with iodine solution. Fig. 12 shows some streaks of Mn sulphide.

Phosphorus.—Limit 0.05 per cent., subsequently raised to 0.06 per cent. In basic steel the phosphorus can be reduced in the steel making, and we had no particular trouble in getting steel within the specified limits. The cast steel slugs were usually made from acid steel and in this case we had difficulty in keeping the phosphorus down, as the phosphorus cannot be reduced in the manufacture and low phosphorus pig-iron was scarce at the end of the war. One rather curious feature in the case of basic steel was that some of the phosphorus occasionally came back into the steel from the slag present in the ladle, and the result was that the last few ingots would contain higher phosphorus. We frequently made a point of taking our chemical drillings from one of the last two ingots, so as to guard against this danger. The ordinary method of analysis was the acid-alkali titration. Stead (J. I. and S. Inst., 1916, No. 2) has recently shown that sulphur (with sufficient manganese) and phosphorus up to about 0.08 per cent., or even 0.10 per cent., may improve the quality of steel. The danger is, of course, that in a steel of, say, 0.10 per cent. P or S there are likely to be segregated patches of much higher P or S content.

Aluminium and Alumina.—Most American firms used aluminium to quieten their steel in the moulds. Aluminium, which is present as such in the steel, is apparently harmless, as it forms a solid solution with the iron. Alumina (Al_2O_3), on the other hand, forms intensely hard angular particles in the steel, and is dangerous, inasmuch as it may form the starting point of a crack. The Al_2O_3 can usually be seen under the microscope (even 0.002 per cent.), and we also used a method of chemical analysis to determine separately the Al and the Al_2O_3. It would no doubt be safer to add the aluminium to the ladle, or, alternately, to use titanium in the ladle.

Copper, Chromium, etc.—These metals were limited to 0.5 per cent. and 0.3 per cent., respectively, but mainly as precautionary measures.

8.—Physical Tests.

These were mainly useful as a check on the chemical analysis and also on the treatment of the steel during forging. The ordinary specifications for forgings called for a 19 tons (42,560 lbs.) yield and a 35 to 49 tons maximum stress (78,000 to 110,000 lbs.). As a rule we found that the breaking load in lbs. was given roughly by the formula—

$$B = 25{,}000 + 1{,}000(C + P) + 300\ Mn$$

so that if a steel was within the chemical specification limits it would be almost certain to give a satisfactory result for breaking load, provided it had not been ill-treated during forging. On

the other hand, there was often considerable difficulty in getting the steel to give a 19 tons yield point. The method used on the standard 2-in. test pieces was to scribe a line with one of the pop-holes as centre and the other (roughly) as radius. The 19 tons per sq. inch load was then applied and taken off. Another line was then scribed with the same centre and radius and the test piece was adjudged to have failed if two distinct lines could be seen (yield 0.01 inches). If there was merely a thickening of the line, the yield was said to be 0.005 inches, and it counted as a partial failure. There is no doubt that this method of testing will show a yield at a much lower point than will the "drop of the beam," the common method in U.S.A. Some of the firms had shown us hundreds of tests when the maximum load was about 90,000 to 100,000, and the yield point by the drop of the beam 50,000 to 55,000 lbs. But when we finally persuaded them to use the scriber method, quite a number of their tests (about half, in fact) would show a distinct yield at 42,500 lbs. There seemed to be a certain amount of plasticity about the steel (possibly due to porosity or inclusions), so that the yield was sometimes only 40 per cent. of the maximum stress. Perhaps for the same reason the steel very rarely showed cracks under the compression test (*i.e.*, crushing a small cylinder, say ½ in. diameter by ½ in. height, to half its original height). The firms generally found that they required at least 0.45 per cent. carbon and 0.60 manganese in order to get the yield point without special treatment. The physical tests on cast steel slugs were rather troublesome, especially as regards elongation, which was fixed at about 12 per cent. As the slugs were shipped to England for forging, and the steel as cast might have an elongation of only, say, 3 or 4 per cent., the firms were allowed to anneal or normalise the selected discs in order to get the required elongation in the test pieces. The process was rather troublesome, but the results were interesting in showing what can be done in improving the qualities of steel castings by heat treatment. If a heat of steel failed to pass the ordinary physical tests (three pieces were usually taken per heat from large heats, and two from small), it was usually sentenced to be normalised (*i.e.*, heated to, say, 850 deg. C., and cooled in the air), or to be annealed (*i.e.*, heated to, say, 850 deg. C., and cooled in the furnace). The heat would then be re-tested. This heat treatment of the whole heat was only necessary in the case of forgings or of small bars (*e.g.*, 3½ in. bars for 18 pdr. shells), when the next operation would be machining. In the case of cast steel slugs or rolled bars for export when subsequent forging would take place in England, it was only necessary for the firms to anneal or normalise the test sections so as to show that the steel could ultimately be made to fulfil specifications. It was rather

curious that most of the American steel would not pass test when cut straight from the bar, even though there was a considerable reduction in size from the ingot. Probably the cooling down and re-heating (with consequent refinement of grain) were required to improve the quality. The annealing of the test sections often caused trouble and delay, and we should have been glad to avoid it if possible.

9.—Air Cooling.

If a heat of forgings still failed to give the required yield point the only resources was to air-cool, *i.e.*, to cool it down through the critical range fairly quickly (say, in 3 to 6 minutes) by means of an air blast, a practice which was allowed under certain restrictions. The air was applied either as a large volume of low pressure air or as an " air-spray " issuing from a number of small holes. There is no doubt that modifications of these processes are likely to be very useful in times of peace. By cooling the steel rather quicker than the ordinary natural cooling, it should be possible to produce sorbite or even troosite instead of pearlite, and develop a considerably greater strength in ordinary steels, without running the risks attendant on quenching. The difficulties of the process are to heat the steel up somewhat above the critical point (say, to 850 deg. C.) without coarsening the grain too much, and then get it into the air blast while still above the critical point, so that the forging will establish its heat gradient from inside to outside, and be falling rapidly in temperature as it passes through the range from 750 deg. to 500 deg. C. No water or oil quenching was allowed for the H.E. shell steel, though occasionally a firm would be suspected of throwing a recalcitrant heat out into the snow whilst it was still red-hot, or of accidentally playing a hose upon it. Incidents such as these were exceptional, but were liable to occur occasionally.

10.—Other Tests: Microscopic Examination.

In cases of doubt it was usual to take a section of the test-bar for microscopic examination. In nine cases out of ten this would show the cause of failure to be want of proper heat treatment; usually the crystalline structure would be too coarse, and a better annealing or normalising would give the required result. If the microstructure showed no apparent defect we usually took drillings from the test-piece and analysed them. The original drillings being taken near the discard, would often have several points higher carbon than the average of the heat, while the lower central portion of the ingot might have several points lower carbon than the average. This shows the importance of keeping the carbon and manganese well above the mini-

mum required strength so as to allow a margin, for variation in composition.

In special cases of investigation it was usual to make:—

(*a*) A general examination.

(*b*) An etching with nitric or sulphuric acid.

(*c*) A sulphur print.

(*d*) Chemical analysis, physical tests and microsections in accordance with the requirements of the case.

Another useful method for showing the phosphorus distributions was brought out during the war by J. C. W. Humphrey. By means of this the lines of flow of the steel during forging can be brought out, though the process requires some practice for its manipulation (v. Fig. 14).

11.—Marking, etc.

In pre-war days it was considered advisable to keep the heat number, ingot number, etc., even on the finished shell, so that in the event of a shell failing at proof the whole life history of the piece of steel could be retraced. Under the exigencies of war these refinements had to be partly abandoned, but the heat number was still carried through to the finished shell as far as possible. The ingot numbers and bar numbers were kept until the bars were broken into shell billets, so that if piping was discovered in a bar, the remaining bars might be fractured. Actually in U.S.A. we found that we could not strictly keep to the original heat numbers in many cases, and we allowed the re-grouping of steel in which the carbon did not vary by more than five points, and manganese plus three times carbon did not vary by more than ten points. In some cases of mixed forgings we tried to group steel by the Brinell hardness test, but although this was found to give a good clue to the breaking load (Brinell's hardness number = twice the maximum load in thousands of pounds), it did not give a very good idea of the chemical composition and of the probable properties of the group after another heat treatment. The French inspectors had a system of marking heats with symbols to show the approximate carbon grouping, and there seems no reason why the British should not use a similar method of standardising. The system of stamping and marking was very elaborate. Each examiner has his workmark which he stamps on the steel to show the particular features which he has inspected and passed. Then there are special stamps such as "Arrow X" meaning "has passed chemical tests and fracture" and "Arrow Diamond" meaning "has passed physical test." One of the minor troubles of inspection was marking the steel so that it could be identified later. Work-marks stamped

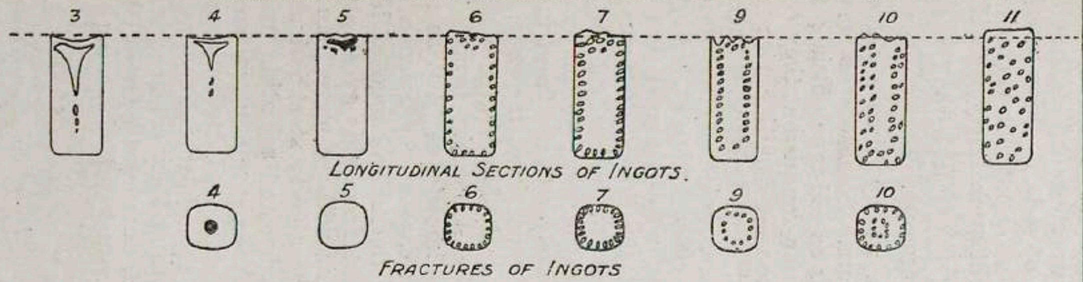
in the steel were protected by a coat of copal varnish, and contract numbers etc., were painted on with a mixture of white lead and boiled linseed oil with a little turpentine. It was found that paper labels could be used if the steel were cleaned and the label put on with Bombay gum (or silicate of soda.) After the gum was dry, the label was varnished with good outdoor varnish. It was found that the silicate of soda will stick fairly well if the steel is warmed to 100 deg. C.

12.—General Impressions.

The Inspection Department was nearly always on good terms with the American manufacturers. Some of the smaller firms were at first inclined to regard us as red-tape officials, who were hampering production, but they soon found that they could often get valuable advice from men who were familiar with manufacturing processes, both in England and America. There is no doubt that the interchange of ideas between British and American engineers and chemists has been of great benefit to the industries of both countries, and it is to be hoped that this will continue after the war. Most of the American firms are generous in giving information, and trust to their enterprise and to the efficiency of their organisation, rather than to the secrecy of their processes in order to keep themselves to the front in the industrial world. After the U.S.A. came into the war, the British manufacturers placed a great deal of information as to their processes, at the disposal of the American firms. The Allies, in fact, pooled their industrial knowledge, just as they pooled their food supplies, but in the case of the French and Italians, the language difficulty made the interchange of ideas rather more difficult. It is hoped that from this great storehouse of industrial experience, Australia will get more than the usual few crumbs, and that we shall be able to start industries on a firm basis of accumulated knowledge and scientific principles. If we are to do this, we must standardise our raw materials, our manufacturing processes and our products and ensure that the quality is satisfactory. We should, therefore, get all the benefit we can from the knowledge and experience gained by the British Inspection Department during the Great War, and apply it to the more congenial task of fostering the industries of peace.

FIG I. BRINELLS SERIES OF INGOT TYPES

Note:- Horizontal dotted line - level of metal in mould immediately after casting



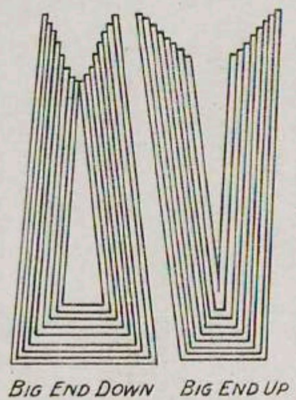


FIG. 2. COOLING OF STEEL IN THE INGOT.

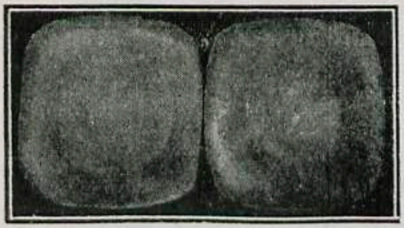


Fig. 3.
Segregated Rings in steel billets.

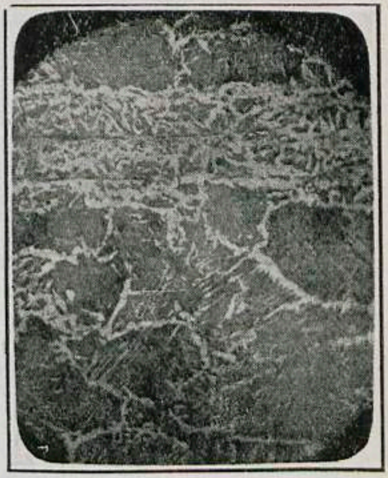


Fig. 4.
Showing ghost line.

Fig. 5.
Showing slag inclusions.

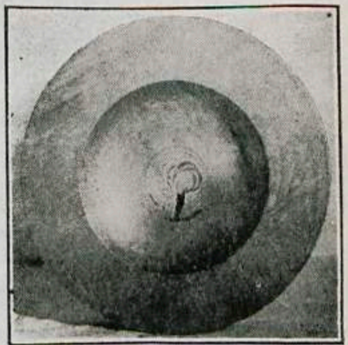


Fig. 6.

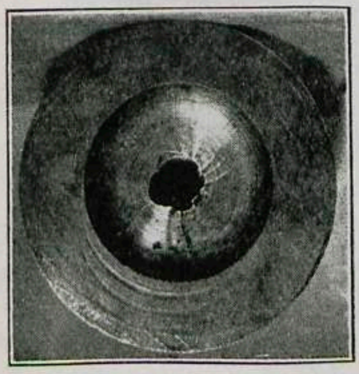
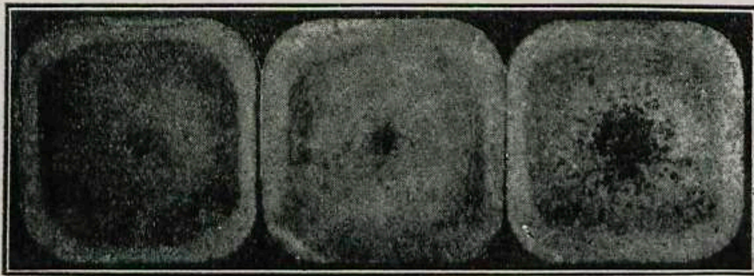


Fig. 7.

Fig. 8.

6, 7 and 8 show secondary pipe in shell forgings.



A *B* *C*

Fig. 9.
Segregation in steel billets.

Fig. 10.
Sulphur Print of round steel billet.

Fig. 11.
Sulphur Print showing streaks of sulphide segregation.

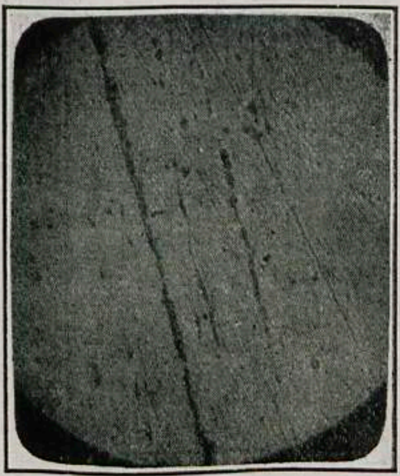


Fig. 12.
Streaks of manganese sulphide in steel.

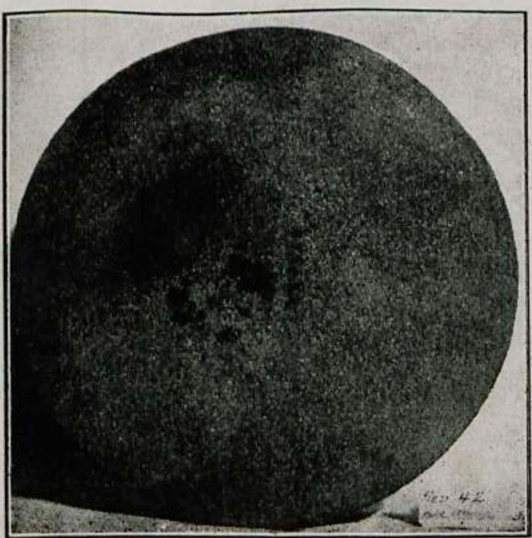


Fig. 13.
Steel billet etched with sulphuric acid showing spongy interior of square shape, also minute crack.

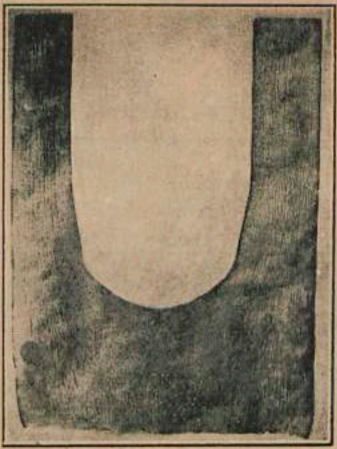


Fig. 14.
Phosphorus Print of shell forging showing lines of flow of metal during working.

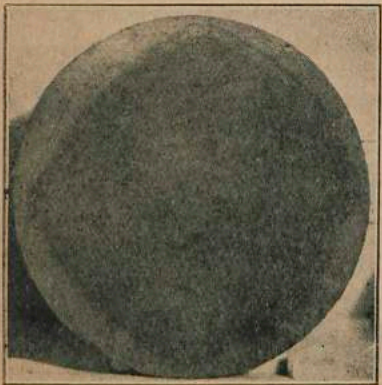


Fig. 15.
(Cross Section.)

Fig. 16.
(Longitudinal Section.)

15 and 16.—Steel billet etched with sulphuric acid showing eccentric patch of spongy steel and segregation near the centre.